U. S. Department of Agriculture Soil Conservation Service Engineering Division Technical Release No. 39 Design Unit May, 1968

HYDRAULICS OF BROAD-CRESTED SPILLWAYS

### PREFACE

This technical release is the first of a series of technical releases envisioned by the Design Branch. The series pertains to the proportioning of earth dams. The main objective of this technical release is to provide a simple procedure for the explicit determination of spillway width while satisfying stability and any capacity requirements.

This technical release is concerned with various aspects for the dimensioning of broad-crested emergency spillways and provides tools for these evaluations. Means are furnished for determining the magnitudes of errors involved in using various approximate procedures and relations. The evaluation of the required emergency spillway capacity is not considered herein.

A number of future technical releases will be concerned with the determination of

- a. required spillway capacity,
- b. optimum dam at a site, and
- c. optimum configuration of structures in a watershed.

Values of parameters used in the preparation of the ES-drawings were obtained by the use of a digital computer. The several programs required for this work were written in FORTRAN IV by the Design Unit. The programs were compiled and executed on IBM 360 equipment by the Washington Data Processing Center, Statistical Reporting Service, USDA.

This technical release was written by Mr. Paul D. Doubt, Head, Design Unit, with the assistance of:

Edwin S. Alling

Hun J. Goon

Stephen M. Boysen

Joan F. Robison

John A. Brevard

Mr. Brevard contributed much to the layout and preparation of the ES-drawings. The technical release was typed by Mrs. Dorothy A. Stewart.

# TECHNICAL RELEASE

# NUMBER 39

# HYDRAULICS OF BROAD-CRESTED SPILLWAYS

Contents	Page
PREFACE	
NOMENCLATURE	
Introduction	1
Relation of $H_{\rm p}$ vs $H_{\rm ec}$ is nearly independent of Q and b	2
Reference Section	3
Principal Graphs	3
Permissible $H_{ec}$ for Various $s_0$ and $v_p$	4 5
Non-Reference Section	5 5 5 5
${ m H_{ec}}$ vs ${ m H_p}$ for Various Lengths, L	8 8 .8 10
Non-Reference Section	10 11 11 12
Critical Slope Corresponding to Q/4	14 15
Non-Reference Section	15 15 15
$H_{ec}$ vs $Q_{c,d}$ for various bottom widths, b	16 17
Examples	17

		Figures	Page
Figure 1.	Maximum val	ues of $(H_{\overline{p}})_b - H_{\overline{p}})_{b=100}$ for $z = 2$ and	
	Case 1 spil	lways for various lengths and in the $45 \le H_{ec} \le 15.0$	12
Figure 2.	Maximum val	ues of $(H_{\overline{p}})_b - H_{\overline{p}}_{b=1.00}$ ) for $z = 2$ and	
	Case 2 spil	lways of various lengths and in the $45 \le H_{ec} \le 15.0$	13
Figure 3.	Maximum val	ues of $(H_{\overline{p}}_{\overline{z}} - H_{\overline{p}}_{\overline{z}=2})$ for $b = 100$ ft	
		spillways of various lengths and in ed intervals of Hec	13
Figure 4.	Maximum val	ues of $(H_{\overline{p}}]_z - H_{\overline{p}}]_{z=2}$ ) for $b = 100$ ft	
	and Case 2	spillways of various lengths and in ed intervals	14
		m-1-1	
·		Tables	
Table 1.		where n = 0.04 $_{2/4}$ but not > 0.04 $_{2/4}$ but n	6
Table 2.	Maximum valuand $s_0 = s_c$	les of permissible $H_{ec}$ where $n = 0.04$ g/4 $z=2,b=100$ but not $> 0.04$	7
Table 3.		the distribution of friction head loss, llways of various bottom profiles	9
Table 4.	Correspondin	ng values of $H_{ec}$ , $s_{c,q/4}$ and $s_{c,q}$	16
•			
		Engineering Standard Drawings	
Drawing No.		Title or Description	
<b>ES-15</b> 8	SPILLWAYS:	Subcritical Water Surface Profiles	
ES-159	SPILLWAYS:	Velocity Head Chart	
ES-170	SPILLWAYS:	Permissible ${\rm H_{ec}}$ for Various ${\rm s_{O}}$ and ${\rm v_{p}}$	
ES-171	SPILLWAYS:	${\tt H}_{\tt ec}$ vs ${\tt H}_{\tt p}$ for Various Lengths, L	
ES-172	SPILIWAYS:	Critical Slope Corresponding to Q/4	
ES-173	HYDRAULICS:	${\rm H_{ec}}\ {\rm vs}\ {\rm Q_{c}}, {\rm d}$ for Various Bottom Widths, b	(z = 0)
ES-174	HYDRAULICS:	${\rm H_{ec}}\ {\rm vs}\ {\rm Q}_{\rm c,d}$ for Various Bottom Widths, b	(z = 2)
ES-175	HYDRAULICS:	${\rm H_{ec}}\ {\rm vs}\ {\rm Q}_{\rm c,d}$ for Various Bottom Widths, b	(z = 3)
ES-176		Effect of n, b, and z on Friction Head Los	
ES-177	SPILLWAYS:	Effect of b and z on Permissible $H_{\mbox{ec}}$	
ES-178	SPILLWAYS:	Effect of b and z on Critical Slope ( $s_{C,Q/L}$	, )
ES-179	SPILLWAYS:	Examples Showing the Interrelation of Draw	wings

#### NOMENCLATURE

```
≡ cross-sectional area of spillway at critical depth, ft<sup>2</sup>
 a_{c}
        ■ bottom width of spillway, ft
 ď
 Ъ1
        b"
        \equiv bottom width of spillway, ft (see ES-173, sheet 4)
 d
        ≡ depth of flow, ft
        ≡ critical depth, ft
d_{c}
ď.
        ≡ critical depth, ft (see page 17)
a_{c,q}
        \equiv critical depth corresponding to a discharge, Q, ft
        \equiv critical depth corresponding to a discharge, Q/h, ft
dc.0/4
        ≡ normal depth corresponding to a discharge, Q, ft
dn.
        = normal depth corresponding to a discharge, Q/4, ft
d_{n,q/4}
        \equiv depth of flow at section x, ft (see ES-158, sheet 9)
d^{x}
        \equiv acceleration of gravity, ft/sec<sup>2</sup>
g
        ≡ friction head loss, ft-lb/lb = ft
h_{f}
h_{f_1}
        = friction head loss, ft (see Table 3, page 9)
        friction head loss in a spillway length, L, and bottom
h<sub>f</sub>,b
          width, b, ft
        = friction head loss in a spillway length, L, and Manning's
hf,n
          roughness coefficient, n, ft
h_{f_{O}}
        ≡ friction head loss, ft (see Table 3, page 9)
        \equiv friction head loss in a spillway length, L, and side slope,
h<sub>f,z</sub>
        = friction head loss in a spillway length, L; bottom width,
          b = 100 ft; side slope, z = 2; and Manning's roughness
          coefficient, n = 0.04, ft
\Delta h_{f}
        = \Delta h_{f,b} + \Delta h_{f,n} + \Delta h_{f,z}, ft (see ES-179, Example 2)
\Delta h_{f,b} = h_{f,b} - h_{f,b=100}, ft
\Delta h_{f,n} = h_{f,n} - h_{f,n=0.04}, ft
\Delta h_{f,z} = h_{f,z} - h_{f,z=2}, ft
H_{e}
       ≡ specific energy head, ft
H_{e}
       ≡ specific energy head at section 2, ft (see ES-158, Example 2)
H_{ec}
       ≡ critical specific energy head, ft
Hec
       ≡ critical specific energy head, ft (see page 17)
```

z ¹

```
≡ critical specific energy head for a spillway with side
Heclz,b
            slope, z, and bottom width, b, ft
          \equiv energy head of the water in the reservoir above the spill-
q^{H}
            way crest, ft
          ≡ energy head of the water in the reservoir above the crest
H<sub>p</sub>
            of a spillway with a bottom width, b, ft
          \equiv energy head of the water in the reservoir over the crest
Hp n
            of a spillway with a Manning's roughness coefficient,
            n, ft
          \equiv energy head of the water in the reservoir over the crest
Hp z
            of a spillway with side slope, z, ft
          \equiv station at the control section (see ES-158, sheet 9)
l<sub>C</sub>
          ≡ station at fictitious control section (see ES-158,
£ c
            Example 2)
          \equiv station at section x (see ES-158, sheet 9)
l_{\rm X}
          ≡ length of the spillway upstream from the control section,
L
            ft
          = length of horizontal portion of spillway, ft (see Table 3,
L_{\rm O}
          = variable integer exponent (see ES-173)
m

    ■ Manning's roughness coefficient

n
          ≡ discharge per foot of spillway bottom width, cfs/ft
q
          ≡ discharge, cfs
Q
          ≡ critical discharge, cfs
Q<sub>C</sub>
          ≡ critical discharge, cfs (see page 17)
Q¦
          \equiv critical discharge, cfs (see ES-173, sheet 4)
Q"
          ≡ critical discharge corresponding to a depth, d, cfs
Qc,d
          ≡ critical slope, ft/ft
s_c
          ≡ critical slope corresponding to a discharge, Q, ft/ft
Sc.Q
          = critical slope corresponding to a discharge, Q/4, ft/ft
<sup>5</sup>c,Q/4
          \equiv critical slope corresponding to a discharge, Q/4, for a
s_{c,Q/4}z.b
             spillway with side slope, z, and bottom width, b, ft/ft
           ≡ slope of spillway bottom, ft/ft
 s_{o}
           \equiv top width of a_c, ft
T_{\rm c}
           ≡ mean velocity of flow, ft/sec
 V
          ≡ critical velocity, ft/sec
 v_c

    permissible velocity, ft/sec

 \nabla_{\mathcal{P}}
           \equiv side slope of the spillway expressed as horizontal dis-
 z
             tance divided by vertical distance, ft/ft
           \equiv side slope of the spillway, ft/ft (see page 17)
```

### TECHNICAL RELEASE

### NUMBER 39

#### HYDRAULICS OF BROAD-CRESTED SPILLWAYS

### Introduction

This technical release pertains to the hydraulics of broad-crested spill-ways, both trapezoidal and rectangular. Such spillways usually function as emergency spillways and may be earth, vegetated, rock, or structural.

Broad-crested spillways may or may not have a control section. Although this technical release is primarily directed toward the evaluation of certain parameters for a spillway having a control section, it contains information concerning the hydraulics of a spillway without a control section.

In this discussion, the inlet channel of a spillway having a control section is considered to have a bottom profile composed of a horizontal slope extending from the control section to the reservoir or of a horizontal slope immediately upstream from the control section and a negative slope (or slopes) extending from the horizontal section to the reservoir. Moreover, only spillways of the same bottom width and side slopes throughout their lengths are considered.

The symbol  $s_{\rm O}$  will be used to designate the various bottom slopes of either the inlet or the exit channel of the spillway. Wherever  $s_{\rm O}$  is used, the text or drawing indicates the particular slope under consideration.

This technical release considers spillways having a wide range of values of:

- 1. spillway bottom widths, b, (25 ft  $\leq$  b  $\leq$  400 ft);
- 2. side slopes, z,  $(0 \le z \le 4)$ ;
- 3. Manning's roughness coefficient, n,  $(0.02 \le n \le 0.08)$ ; and
- 4. inlet channel lengths, L.

### Procedures are presented for:

- l. the evaluation of the permissible critical specific energy head,  $H_{eC}$ , corresponding to a permissible velocity,  $v_D$ , and exit channel bottom slope,  $s_O$ ;
- 2. the evaluation of the head,  $H_p$ , in the reservoir over the crest of the spillway corresponding to the critical specific energy head,  $H_{ec}$ ;
- 3. the evaluation of the required spillway bottom width, b, corresponding to the critical specific energy head,  $H_{\rm ec}$ , and the required discharge, Q; and
- 4. the evaluation of the critical slope,  $s_{c,Q/4}$ , corresponding to the discharge Q/4 where Q is the discharge corresponding to  $H_{\rm ec}$ .

The procedures yield answers quickly and with sufficient accuracy for final design. Since results can be obtained quickly, the procedures can be used equally advantageously for planning.

Although numerous ES-drawings are presented in this technical release, the usual spillway design requires the use of only one sheet from each of the ES-drawings 170, 171, and 174. Other graphs and ES-drawings have been included for two reasons:

- 1. to aid in the evaluation of design parameters for spillways of unusual dimensions, and
- 2. to provide a method of establishing the magnitude of error incurred by the various approximations employed.

A subsequent technical release will give procedures for evaluating, prior to the determination of the spillway width, b, the required capacity, Q, corresponding to a head,  $H_{\rm p}$ , over the crest. This evaluation involves reservoir routing.

# Relation of $\mathbf{H}_{\mathbf{p}}$ vs $\mathbf{H}_{\mathbf{e}c}$ is nearly independent of Q and b

Usually, a spillway has a control section. When a spillway has a control section, the depth of flow and the specific energy head at the control section for a discharge, Q, are equal to the critical depth and the critical specific energy head corresponding to Q, respectively. The critical specific energy head,  $H_{\rm ec}$ , is the minimum specific energy head for the discharge, Q. Thus, for the discharge, Q, the specific energy head,  $H_{\rm e}$ , at any section upstream (or downstream) from the control section is greater than  $H_{\rm ec}$ . Moreover, it can be shown that the friction head loss,  $h_{\rm f}$ , in conveying the discharge, Q, from the reservoir to the control section is the difference in the head,  $H_{\rm p}$ , over the crest and the critical specific energy head,  $H_{\rm ec}$ , i.e.

$$h_{f} = H_{p} - H_{ec} \tag{1}$$

Writers discussing the hydraulics of spillways have often related  ${\rm H}_p$  to either the parameter  ${\rm q}=\frac{Q}{b}$  or the parameter  ${\rm d}_{c,Q}$ . Since the relation of  ${\rm H}_{ec}$  vs  ${\rm H}_p$  is more nearly independent of the values of Q and b than the relation of q vs  ${\rm H}_p$  or  ${\rm d}_{c,Q}$  vs  ${\rm H}_p$ , this technical release uses  ${\rm H}_{ec}$  as the fundamental parameter instead of q or  ${\rm d}_{c,Q}$ . Insight into the reason for the near independence of the relation of  ${\rm H}_{ec}$  vs  ${\rm H}_p$  with respect to Q and b, as compared to the relation of either q vs  ${\rm H}_p$  or  ${\rm d}_{c,Q}$  vs  ${\rm H}_p$ , can be obtained by observing

$$H_p = d_{c,q} + \frac{Q^2}{2g a_c^2} + h_f = H_{ec} + h_f$$
 (2)

From Eq. (2) it is evident that for a given  $H_{ec}$ , the value of  $H_p$  is affected by the parameters which affect  $h_f$ ; for a given  $d_{c,Q}$ , the value of  $H_p$  is affected by the parameters which affect the critical velocity head,  $\frac{Q^2}{2g~a_c^2}$ , and  $h_f$ ; and for a given q, the value of  $H_p$  is affected by the parameters which affect  $d_{c,Q}$ ,  $\frac{Q^2}{2g~a_c^2}$ , and  $h_f$ .

The near independence of the relation of  $H_{ec}$  vs  $H_p$  from Q and b is desirable since either Q, b, or both are often unknown prior to a reservoir routing. Although the relation of  $H_{ec}$  vs  $H_p$  is nearly independent of Q and b, one should observe there is a definite relation of  $H_{ec}$ , Q, and b.

# Reference Section (b = 100 ft, z = 2, n = 0.04)

Many of the parameters needed in spillway design can be readily evaluated for a preselected cross section. Writers have often evaluated parameters for spillways on the basis of a preselected cross section of infinite width. In this technical release a preselected spillway cross section of b = 100 ft and z = 2 with n = 0.04 was chosen as more nearly representative of actual spillways. This preselected cross section is called the Reference Section.

Using the Reference Section it is possible to obtain values of certain parameters which are approximately correct for the actual cross section. The values of these parameters can be easily refined if thought desirable.

# Principal Graphs

Some parameters for the Reference Section can be evaluated by the four principal drawings described below.

- 1. Permissible  $H_{ec}$  vs exit channel bottom slope,  $s_0$ , with a family of permissible velocity,  $v_p$ -curves. (ES-170)
- 2.  $H_p$  vs  $H_{ec}$  with a family of spillway length, L-curves, for selected bottom profiles. (ES-171)
- 3. Critical slope,  $s_{c,q/4}$  vs  $H_{eq}$ . (ES-172)
- 4. Q vs  $H_{ec}$  with families of spillway bottom widths, b, and critical depths,  $d_{c,q}$ . (ES-174)

Additional graphs are included to show the effects on these parameters when b, z, or n differs from that of the Reference Section.

# Permissible $H_{ec}$ for Various $s_0$ and $v_p$ (ES-170)

Velocities in structural spillways and spillways constructed in competent rock often are not of magnitudes which require attention. An earth or a vegetated spillway can have velocities in its exit channel of magnitudes which cause instability and require some forethought during design. The graphs of ES-170 pertain to this aspect of spillway design.

The values given by ES-170 are the result of determining the critical specific energy head,  $\rm H_{ec}$ , corresponding to a discharge, Q, which is equal to the normal discharge having a velocity of  $\rm v_p$  in an exit channel defined by the parameters  $\rm s_0$ , n, z, and b. This  $\rm H_{ec}$  is the permissible  $\rm H_{ec}$  or the permissible critical specific energy head corresponding to the permissible velocity,  $\rm v_p$ , and exit channel bottom slope,  $\rm s_0$ .

The value of the permissible  $H_{\rm ec}$  is increased by any one or any combination of the following changes in parameters:

- 1. decreasing so,
- 2. increasing vp, and
- 3. increasing n.

The stage-discharge relation of a spillway is required in problems of reservoir routings. This relation is readily obtained through the range of discharges for which the spillway has a control section. In this technical release, when a spillway has a control section this range is frequently taken as Q/4 to Q.

To ensure that a spillway, with  $z \ge 1$ , has a control section over the range of discharges from Q/4 to Q (see  $H_{ec}$  vs  $s_{c,q/4}$  - ES-172), the slope,  $s_{O}$ , immediately downstream from the control section must be equal to or greater than  $s_{c,q/4}$  and be of sufficient length to prevent tailwater effects at the control section. The maximum values of  $v_{D}$  and n are established by the spillway site. Thus, given  $v_{D}$  and n, a spillway with a control section for the range of discharges being considered has a maximum value of permissible  $H_{ec}$  when  $s_{O} = s_{c,q/4}$ . Frequently the value of  $s_{O}$  is not required to be greater than 0.04. Thus, if  $s_{c,q/4} > 0.04$  and  $s_{O}$  is taken as 0.04, the break in grade is not a control section for all discharges in the interval q/4 to q.

Table 1 shows, for a spillway having a control section for a range of discharges and for n = 0.04, the minimum values of  $s_0$  and the maximum values of permissible  $H_{\rm ec}$  corresponding to various values of  $v_{\rm p}$ .

Values of the exit channel bottom slope,  $s_0$ , were taken as  $s_{c,Q/4}$  except when  $s_{c,Q/4} > 0.04$  in which case  $s_0$  was taken as 0.04. The values of the permissible  $H_{ec}$  and minimum  $s_0$  for the Reference Section are shown in the shaded blocks.

Table 2 shows, for a spillway having a control section for the range of discharges and for n = 0.04, the value of permissible  $H_{ec}$  obtained by using  $s_0 = s_{c,q/4}$  of the Reference Section in place of  $s_{c,q/4}$  of a non-Reference Section.

## Reference Section

For the Reference Section, the relation of permissible  $H_{ec}$ ,  $v_p$ , and  $s_o$  is given by ES-170, sheet 1. The drawing contains a curve which gives the relation of the critical specific energy head,  $H_{ec}$ , and the critical slope,  $s_{c,q/4}$ , where Q is the discharge corresponding to  $H_{ec}$ . This curve was obtained by equating the normal depth of flow,  $d_{n,q/4}$ , to the critical depth,  $d_{c,q/4}$ , to establish the value of  $s_{c,q/4}$ .

### Non-Reference Section

n = 0.02. - When n = 0.02, the relation of permissible  $H_{ec}$ ,  $v_p$ , and  $s_0$  is given by ES-170, sheet 2. The graph permits the evaluation of the permissible  $H_{ec}$  for spillways with n = 0.02 in the exit channel. The three curves labeled  $s_{c,q/4}$  for n = 0.02, n = 0.03, and n = 0.04 are superimposed on this graph. The values of n = 0.02, n = 0.03, and n = 0.04 were used in determining the normal depth of flow,  $d_{n,q/4}$ , which was equated to the critical depth,  $d_{c,q/4}$  to establish the value of  $s_{c,q/4}$  where Q is in correspondence with the critical specific energy head,  $H_{ec}$ .

 $\frac{n \neq 0.04 \text{ or } 0.02.}{n}$  - When the value of n is neither 0.04 nor 0.02, the relation of the permissible  $H_{ec}$ ,  $v_p$ , and  $s_o$  is given by ES-170, sheet 1 by redesignating the abscissa as  $\frac{0.04}{n}^2 s_o$  or sheet 2 by redesignating the abscissa as  $\frac{0.02}{n}^2 s_o$ .

<u>z ≠ 2, b ≠ 100 ft.</u> - The permissible  $H_{ec}$  values for intervals of 25 ≤ b ≤ 400, 0 ≤ z ≤ 4, 2 ≤  $v_p$  ≤ 15, and wide ranges of  $s_0$  and n can be evaluated by use of the information given in ES-177.

Table 1. Maximum values of permissible  $H_{ec}$  where n = 0.04 and  $s_0=s_{c,q/4}$  but not > 0.04.  $v_p=ft/sec$ , b = ft, z = ft/ft,  $H_{ec}=ft$ ,  $s_0=ft/ft$ 

z	$v_p$	2			3			4		
-	Ъ	25	100	400	25	100	400	25	100	400
0	H <sub>ec</sub>	0.203 0.04	0.202 0.04	0.202 0.04	0.402 0.04	0.398 0.04	0.396 0.04	0.652 0.04	0.643 0.04	0.641 0.04
1	H <sub>ec</sub>	0.203 0.04	0.202 0.04	0.202 0.04	0.402 0.04	0.397 0.04	0.396 0.04	0.652 0.04	0.643 0.04	0.641 0.04
2	H <sub>ec</sub>	0.203	0.202 0.04	0.202 0.04		0.398 0.04	0.397 0.04	0.656 0.04	0.644 0.04	0.641 0.04
3	H <sub>ec</sub>	0.204 0.04	0.202 0.04	0.202 0.04	0.405 0.04	0.398 0.04	0.397 0.04	0.661 0.04	0.645 0.04	0.641 0.04
4	H <sub>ec</sub>	0.205 0.04	0.202 0.04	0.202 0.04	0.407 0.04	0.399 0.04	0.397 0.04	0.666 0.04	0.647 0.04	0.642 0.04

z	$v_p$		5			6			7	
-	Ъ	25	100	400	25	100	400	25	100	400
0	H <sub>ec</sub>	0.983 0.0375	0.970 0.0 <b>3</b> 70	0.961 0.0 <b>3</b> 69	1.43 0.0337	1.41 0.0327	1. <b>3</b> 9 0.0 <b>3</b> 26	1.98 0.0306	1.92 0.0297	1.89 0.0295
1	H <sub>ec</sub>	1.00 0.0366	0.970 0.0 <b>3</b> 70	- 1		1	1.39 0.0325	2.01 0.0293	1.92 0.0294	1.90 0.0293
2	H <sub>ec</sub>	1.01 0.0364	0.975 0.0369		1		1.40 0.0324	-	1.92 0.0294	1.90 0.029 <b>3</b>
3	H <sub>ec</sub>	1.03 0.0360	0.983 0.0367	0.970 0.0367	1	1.43 0.0323	1.41 0.0324	2.12 0.0284	1.94 0.0291	1.92 0.0292
4	H <sub>ec</sub>	1.05 0.0358	0.989 0.0 <b>3</b> 66	0.977 0.0 <b>3</b> 66		1.43 0.0322	1.41 0.0322	2.19 0.0280	1.98 0.0290	1.92 0.0291

z	$v_p$	v <sub>p</sub> 8				9			10		
"	b	25	100	400	25	100	400	25	100	400	
0	H <sub>ec</sub>	2.62 0.0283	2.50 0.0272	2.48 0.0270	<b>3.3</b> 6 0.0267	<b>3.</b> 19 0.0252	3.15 0.0249	4.23 0.0252	3.94 0.0236	3.89 0.0233	
1	H <sub>ec</sub>	2.65 0.0269	2.52 0.0268	2.48 0.0268	3.42 0.0249	3.20 0.0248	3.15 0.0248	4.31 0.0233	3.99 0.0231	3.89 0.0231	
2	H <sub>ec</sub>		2.54 0.0268			3.24 0.0246	3.19 0.0247	4.51 0.0225	4.04 0.0229	3.91 0.0230	
3	H <sub>ec</sub>	2.86 0.0257	2.57 0.0265			3.29 0.0245	3.19 0.0247	4.71 0.0219	4.07 0.0228	3.93 0.0230	
4	H <sub>ec</sub>	2.95 0.0254	2.60 0.0264	2.50 0.0267	3.83 0.0232	3.32 0.0242	<b>3.</b> 19 0.0247	4.95 0.0214	4.18 0.0225	3.95 0.0230	

Table 2. Maximum values of permissible  $H_{ec}$  where n = 0.04 and  $s_0 = s_{c,0/4}$   $c_{z=2,b=100}$  but not > 0.04.  $c_{p} = ft/sec$ , b = ft, z = ft/ft,  $c_{ec} = ft$ ,  $c_{p} = ft/ft$ 

			$v_p = ft$	/sec, b	= ft,	z = ft/s	ft, H <sub>ec</sub>	= ft,	$s_0 = ft$	/ft
z	$v_p$		2			3			4	
	Ъ	25	100	400	25	100	400	25	100	400
0	H <sub>ec</sub>	0.203	0.202	0.202	0.402	0.398	0.396	0.652	0.643	0.641
1	H <sub>ec</sub>	0.203	0.202	0.202	0.402	0.397	0.396	0.652	0.643	0.641
2	H <sub>ec</sub>	0.203	0.202	0.202	0.403	0.398 0.04	0 <b>.3</b> 97	0.656	0.644	0.641
3	H <sub>ec</sub>	0.204	0.202	0.202	0.405	0.398	0.397	0.661	0.645	0.641
4	H <sub>ec</sub>	0.205	0.202	0.202	0.407	0.399	0.397	0.666	0.647	0.642
z	v <sub>p</sub>	5			6			7		
<u> </u>	Ъ	25	100	400	25	100	400	25	100	400
0	H <sub>ec</sub> s <sub>o</sub>	0.990	0.970	0.962	1.46	1.42	1.40	2.02	1.93	1.90
1	H <sub>ec</sub> s <sub>o</sub>	0.995	0.972	0.970	1.45	1.42	1.39	2.00	1.92	1.90
2	H <sub>ec</sub> so	1.01	0.975 0.0369	0.975	1.47	1.42 0.0325	1 <b>.3</b> 9	2.04	1.92 0.0294	1.90
3	H <sub>ec</sub>	1.02	0.979	0.970	1.49	1.42	1.40	2.08	1.93	1.91
4	H <sub>ec</sub>	1.03	0.982	0.972	1.52	1.43	1.40	2.12	1.97	1.92
ļ					γ					
z	v <sub>p</sub>		8	1.00		9	T ,	10		
	Ъ	25	100	400	25	1.00	400	25	100	400
0	H <sub>ec</sub> s <sub>o</sub>	2.71	2.52	2.49	3.51	3.22	3.17	4.49	4.00	3.92
1	H <sub>ec</sub>	2.67	2.52	2.48	3.45	3.21	3.16	4.36	4.00	3.91
2	H <sub>ec</sub>	2.72	2.54 0.0268	2.48	3.55	3.24 0.0246	<b>3.</b> 19	4.47	4.04 0.0229	3.92
3	H <sub>éc</sub> s <sub>o</sub>	2.78	2,56	2.50	3.65	<b>3.</b> 27	<b>3.</b> 19	4.58	4.06	3.94
4	H <sub>ec</sub>	2.86	2.58	2.50	3.75	3.32	3.20	4.75	4.15	3.95

Approximate values of permissible  $H_{ec}$ , when  $25 \le b \le 400$  and  $0 \le z \le 4$ , may be obtained from ES-170, sheet 1. When they are so obtained, the maximum error can be ascertained from Table 1 for  $2 \le v_p \le 10$ . For example; if b = 30, z = 3 and  $v_p = 6.0$ , ES-170 gives maximum permissible  $H_{ec} = 1.42$  ft. Table 1 shows that maximum permissible  $H_{ec}$  is less than 1.52 ft since 25 < (b = 30) < 100. The error in the maximum permissible  $H_{ec}$  is less than 0.1 ft. The error in obtaining the maximum permissible  $H_{ec}$  from ES-170, sheet 1 is the greatest for the higher values of  $v_p$  and lower values of b.

# ${\rm H_{ec}}$ vs ${\rm H_{p}}$ for Various Lengths, L (ES-171)

Except for the higher values of  $v_p$  and the lower values of  $s_o$ , the relation of the permissible  $H_{ec}$  and the corresponding nexus of parameters  $(v_p,\,s_o,\,b,\,z,\,n)$  used in design of an earth or a vegetated spillway is nearly independent of Q and b. The relation of  $H_{ec}$  and  $H_p$  is also nearly independent of Q and b.

### Reference Section

For an  $H_{\rm ec}$  and a length of spillway upstream from the control section, the corresponding value of  $H_{\rm p}$  is obtained from ES-171. The drawing considers only spillways having the Reference Section. Each sheet is for a bottom profile as specified by the case number.

Effect of bottom profiles. - For a spillway with the Reference Section and of length, L, the effect of varying the bottom profile on the value of  $\rm H_{\rm p}$  corresponding to a particular value of  $\rm H_{\rm ec}$  can be ascertained from the various sheets of ES-171. Table 3 gives the values of friction head loss,  $\rm h_{\rm f}$ , for spillways of various bottom profiles when the spillway length is 400 ft and  $\rm H_{\rm ec}$  = 4 ft.

Table 3. Values and the distribution of friction head loss,  $h_f$ , for spillways of various bottom profiles

$H_{ec} = 4.0 \text{ ft}$ $L = 400 \text{ ft}$ $n = 0.04$ $z = 2$ $b = 100 \text{ ft}$	$H_{oo} = 4.0 \text{ ft}$	L = 400  ft	n = 0.04	z = 2	b = 100 ft
--	---------------------------	-------------	----------	-------	------------

Case	H <sub>p</sub> , ft	h <sub>f</sub> , ft	L <sub>O</sub> , ft	h <sub>fo</sub> , ft	h <sub>f1</sub> , ft
2	4.62	0.62	30	0.28	0.34
3	4.47	0.47	30	0.28	0.19
4	4.71	0.71	50	0.40	0.31
5	4.58	0 <b>.5</b> 8	50	0.40	0.18
6	4.91	0.91	100	0.65	0.26
7	4.79	0.79	100	0.65	0.14
8	4.61	0.61	50	0.40	0.21
9	4.53	0.53	50	0.40	0.13

 $L_0 \equiv length of horizontal portion of spillway - ft$ 

 $h_f \equiv \text{total friction head loss in L, } h_f = h_{f_0} + h_{f_1} - \text{ft}$ 

 $h_{f_O} \equiv friction head loss in L_O - ft$ 

 $h_{f}$  = friction head loss in L - L<sub>o</sub> - ft

The value of  $H_p$  varies between the extreme values of 4.47 ft (Case 3) and 4.91 ft (Case 6).

The friction head loss,  $h_{\rm f}$ , varies between 0.47 ft and 0.91 ft. The major portion of the friction head loss, as is often true, occurs in conveying the discharge through the horizontal part of the spillway. For Case 3 and Case 6, the head loss,  $h_{\rm f_0}$ , required to convey the discharge through the horizontal portion of the spillway is  $h_{\rm f_0}=0.28$  ft and  $h_{\rm f_0}=0.65$  ft, respectively. For Cases 3 and 6,  $h_{\rm f_0}$  is over 50 percent of the total head loss in the 400 ft long spillway. In Case 3 the head loss upstream of the horizontal part of the spillway is  $h_{\rm f_1}=0.19$  ft while in Case 6 this head loss is  $h_{\rm f_1}=0.26$  ft.

The left-most curve of ES-171 labeled either L = 30, 50, or 100 is related to the upstream section of the horizontal part of the spillway. At any particular  $H_{ec}$ , the ratio of the distance from the left-most curve to the line for L = 0 to the distance from the curve for the spillway length, L, to the line for L = 0 is the ratio  $\frac{h_{fo}}{h_{f}}$ . For

example, using Case 6 and  $H_{ec}=4.0$  ft, the values of  $H_p$  at L=100 ft and L=400 ft are 4.65 ft and 4.91 ft. Thus  $\frac{h_{f_0}}{h_r}=\frac{0.65}{0.91}=71$  percent.

The ratio of the distance from the curves for L = 100 ft and L = 400 ft to the line for L = 0 is also 71 percent at  $H_{ec}$  = 4.0. These graphs give visually the proportion  $\frac{h_{fo}}{h_f}$ .

From Table 3 one can observe that the variation in the depth of the forebay upstream from the horizontal portion of the spillway often has a negligible influence on the  $\rm H_p$  value. For example, when  $\rm L=400~ft$  and  $\rm H_{ec}=4.0~ft$ , the  $\rm H_p$  value for Case 8 is 0.10 ft smaller than the  $\rm H_p$  value for Case 4.

 $H_{\rm ec}$  vs  $H_{\rm p}$  for bottom profiles differing from those in ES-171. - The relation of  $H_{\rm ec}$  vs  $H_{\rm p}$  for spillways with bottom profiles differing from those given by ES-171 may be approximated by the use of ES-171; however, if a closer evaluation is desired, the relation may be obtained from the basic information given in ES-158 and ES-159.

ES-158 and ES-159 are for spillways with the Reference Section. The drawings, ES-158 and ES-159, can be used in determining the relation of  $\rm H_{ec}$  vs  $\rm H_p$  for spillways not having a control section.

### Non-Reference Section

The friction head loss, h<sub>f</sub>, occurring in a spillway having a non-Reference Section and a bottom profile of either Case 1 or Case 2, as defined by ES-171, may be obtained from ES-176. In ES-176, the effect on the friction head loss is considered when the parameters n, b, and z are varied in the following ranges:

- 1.  $0.02 \le n \le 0.08$ ,
- 2.  $25 \le b \le 400$ , and
- 3.  $1 \le z \le 4$ .

Observe that for some curves in ES-176 the maximum  $h_{\rm f}$  exists at values of  $H_{\rm ec}$  < 15 ft. For example, see ES-176, sheet 2, the curve labeled n=0.04, L=30 ft shows a maximum for  $h_{\rm f}$  at  $H_{\rm ec}$  < 15 ft. The first reaction by some is that this curve might be in error, since erroneously, "More water can be conveyed at less friction loss for  $H_{\rm ec}=10$  ft than for  $H_{\rm ec}=5$  ft." One should recall that although the units of  $h_{\rm f}$  are generally given and viewed as feet,  $h_{\rm f}$  is actually a rate of energy loss per pound of water being conveyed, i.e. ft-lb/lb. Normally,

hydraulic computations involving energy relations are made on the basis of per pound of water and the term total energy loss usually refers to the total energy loss for each pound of water. The total energy loss through the spillway in one second of time for all the pounds of water being conveyed is actually 62.4 Q  $h_{\rm f}$ .

Effect of Manning's n. - From ES-176, sheets 1-3, one can observe that the value of Manning's roughness coefficient, n, has considerable effect on the value of  $h_f$  and hence  $H_p$ . Sheets 1, 2, and 3 of ES-176 can be used for the evaluation of the friction head loss,  $h_f$ , when n  $\neq$  0.04.

When n  $\neq$  0.04 and s<sub>0</sub> = 0, the abscissa, ( $\ell_c - \ell_x$ ), of ES-158, sheet 1 may be redesignated

$$\frac{n^2(\ell_c - \ell_x)}{0.0016} \tag{3}$$

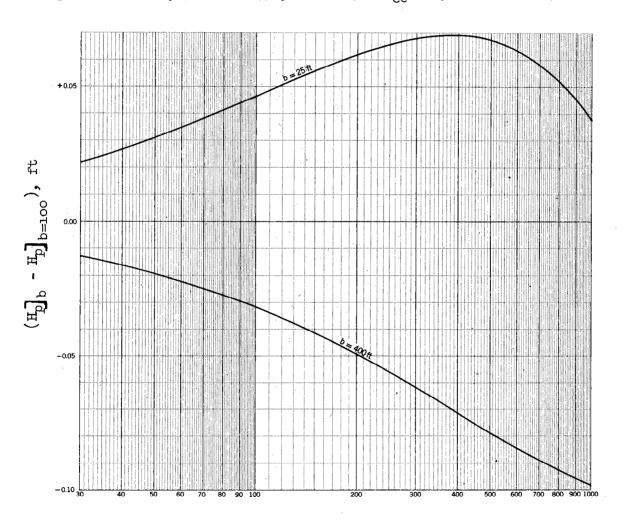
to evaluate the depth of flow at a section a distance,  $(\ell_{\rm C}$   $-\ell_{\rm X})$ , upstream from a control section. A similar redesignation of the abscissas of the sheets 2-8 of ES-158 would be incorrect.

Effect of bottom width, b. - As previously mentioned, for a particular value of  $H_{ec}$ , the value of b within the interval of 25  $\leq$  b  $\leq$  400 has minor effect on the value of  $H_p$ . For Cases 1 and 2, the value of  $h_f$  can be ascertained from ES-176, sheets 4 and 5 for any b within the interval 25  $\leq$  b  $\leq$  400.

Figure 1 shows, for z=2 and Case 1, the maximum values of  $(H_p)_b - H_p)_{b=100}$ ) for b=25 ft and 400 ft, for the interval  $0.45 \le H_{ec} \le 15$  and for various spillway lengths, L. For Case 1, the maximum error in taking  $H_p)_b = H_p)_{100}$  is less than 0.10 ft within the region  $25 \le b \le 400$ ,  $30 \le L \le 1000$ , and  $0.45 \le H_{ec} \le 15$ .

Figure 2 shows, for z = 2 and Case 2, the maximum error in taking Hp]  $_b$  = Hp]  $_{100}$  is less than 0.04 ft within the region 25  $\leq$  b  $\leq$  400, 30  $\leq$  L  $\leq$  750, and 0.45  $\leq$  H $_{ec}$   $\leq$  15.

Effect of side slope, z. - For a particular value of  $H_{ec}$ , the value of z, within the interval  $1 \le z \le 4$ , has a minor effect on the value of  $H_p$ . For Cases 1 and 2, the value of  $h_f$  can be ascertained for any z, within the interval  $1 \le z \le 4$ , from ES-176, sheets 6 and 7. Figure 3 shows, for b = 100 and Case 1, the maximum values of  $(H_p)_z - H_p)_{z=2}$  for z = 1 and 4 for the intervals  $0.45 \le H_{ec} \le 4.0$  and  $0.45 \le H_{ec} \le 15$  and for various spillway lengths, L. Figure 4 shows, for b = 100 and Case 2, the maximum error in taking  $H_p)_z = H_p)_2$  is less than 0.09 ft within the region  $1 \le z \le 4$ ,  $30 \le L \le 750$ , and  $0.45 \le H_{ec} \le 15$ .



Spillway Length, L, ft

Figure 1. Maximum values of  $(H_p)_b - H_p)_{b=100}$  for z=2 and Case 1 spillways of various lengths and in the interval 0.45  $\leq H_{ec} \leq 15.0$ 

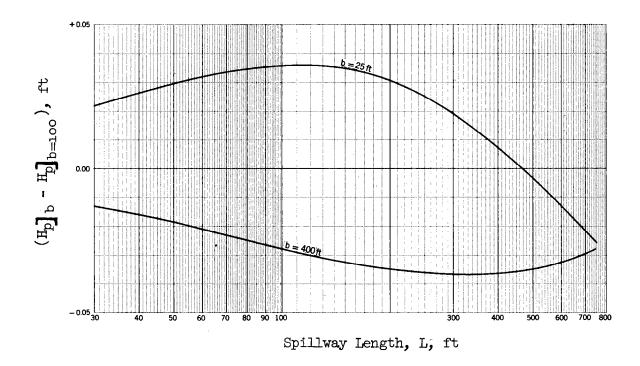
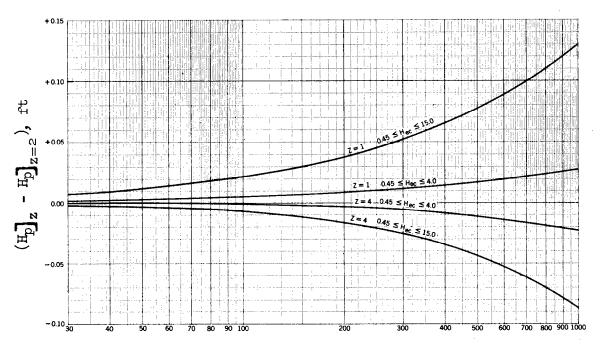
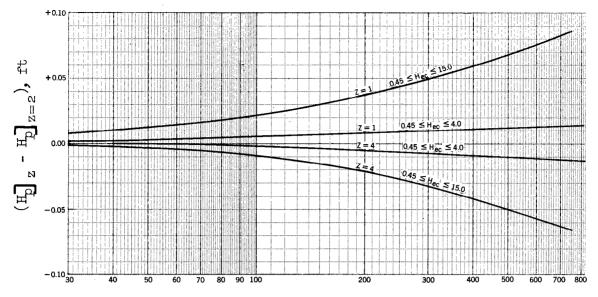


Figure 2. Maximum values of  $(H_p]_b - H_p]_{b=100}$  for z=2 and Case 2 spillways of various lengths and in the interval  $0.45 \le H_{ec} \le 15.0$ 



Spillway Length, L, ft

Figure 3. Maximum values of  $(H_p)_z - H_p)_{z=2}$  for b = 100 ft and Case l spillways of various lengths and in the indicated intervals of  $H_{ec}$ 



Spillway Length, L, ft

Figure 4. Maximum values of  $(H_p)_z - H_p)_{z=2}$  for b = 100 ft and Case 2 spillways of various lengths and in the indicated intervals

# Critical Slope Corresponding to Q/4 (ES-172)

A control section exists at a break in grade if;

- 1. the slope upstream from the break in grade is less than critical slope and is sufficiently long, and
- 2. the slope downstream from the break in grade is greater than or equal to the critical slope, and is sufficiently long to prevent tailwater effects at the control section.

Critical slope corresponding to the discharge, Q, is defined as that slope which causes the discharge, Q, to be conveyed as uniform flow at a depth equal to critical depth (i.e.  $d_{n,Q} = d_{c,Q}$ ).

The critical slope is associated with a discharge, Q, and when the discharge is changed, the critical slope is changed. Further, the depth of flow at the control section is the critical depth corresponding to the discharge, Q.

For the range of b's, z's and depths of flow being considered in this technical release the critical slope usually decreases as the discharge is increased. When this is true, a control section is ensured for a range of discharges from Q/4 to Q if the slope immediately downstream from the control section is greater than or equal to the critical slope corresponding to Q/4. Symbolically the critical slope corresponding to Q/4 is written  $s_{c,Q/4}$  and is in correspondence with  $H_{ec}$  where  $H_{ec}$  is in correspondence with  $H_{ec}$ 

Reference Section

For an Hec the corresponding value of sc.Q/4 is obtained from ES-172.

Non-Reference Section

A control section is ensured for the range of discharges of Q/4 to Q in the regions

- (1)  $1 \le z \le 4$ ,  $25 \le b \le 400$ , and  $0.45 \le H_{ec} \le 15$ ;
- (2) z = 0,  $40 \le b \le 400$ , and  $0.45 \le H_{ec} \le 15$ ; and the region
- (3) z = 0,  $25 \le b \le 400$ , and  $0.45 \le H_{ec} \le 9.8$

by taking the exit channel bottom slope  $s_0 \ge s_{0,0/4}$ .

When z = 0, b < 40, and  $9.8 \le H_{ec} \le 15$ , taking  $s_0 = s_{c,Q/4}$  does not ensure a control section for the range of discharges from Q/4 to Q.

The relation of  $H_{ec}$  vs  $s_{c,q/\nu}$  for the lower values of  $H_{ec}$  but greater than 0.45, is nearly independent of Q and b for the range of values  $25 \le b \le 400$  and  $0 \le z \le 4$ .

Effect of n. - When the value of n ≠ 0.04, z = 2, and b = 100, the critical slope,  $s_{c,q/4}$ , corresponding to an  $H_{ec}$  can be obtained by redesignating the abscissa of ES-172, sheet 1 as  $\left[\frac{0.04}{n}\right]^2 s_{c,q/4}$ .

When the value of n ≠ 0.04, z = 0, and 25 ≤ b ≤ 400, the critical slope,  $s_{c,q/4}$ , corresponding to an  $H_{ec}$  can be obtained by redesignating the abscissa of ES-178, sheet 1 as  $\left[\frac{0.04}{n}\right]^2 s_{c,q/4}$ .

The value of  $s_{c,q/4}$   $J_{z,b}$  for any n can be obtained from ES-178, sheet 2, within the region  $1 \le z \le 4$ ,  $25 \le b \le 400$ , and  $0.45 \le H_{ec} \le 15$ .

Effect of b and z. - The value of  $s_{c,Q/4}$ , as obtained from ES-172, is in error by less than 0.001 within the region 25  $\leq$  b  $\leq$  400, 2  $\leq$  z  $\leq$  4, and 0.45  $\leq$  Hec  $\leq$  15.0.

The value of  $s_{c,q/4}$  for z=0 and within the region 25  $\leq$  b  $\leq$  400 and 0.45  $\leq$  H<sub>ec</sub>  $\leq$  15 is given by sheet 1, ES-178.

The value of  $s_{c,q/4}$  for any n and within the region  $25 \le b \le 400$ ,  $1 \le z \le 4$ , and  $0.45 \le H_{ec} \le 15$  is shown by sheet 2 of ES-178.

Values of  $s_{c,q/4}$ , along with  $s_{c,q}$ , for the extremes of the region  $25 \le b \le 400$ ,  $0 \le z \le 4$ , and  $0.45 \le H_{ec} \le 15$  are given in Table 4.

			π	U•U4		
_	H <sub>ec</sub> , ft	b, ft	Z	s <sub>c,Q/4</sub> , ft/ft	s <sub>c,Q</sub> , ft/ft	
_	0.45	25	0	0.04797	0.03593	
	0.45	400	0	0.04741	0.03488	
	0.45	25	4	0.04735	0.03529	
	0.45	400	4	0.04737	0.03484	
	15	25	0	0.02126	0.02368	_
	15	400	0	0.01511	0.01154	
	15	25	4	0.01523	0.01259	
	15	400	4	0.01471	0.01111	

Table 4. Corresponding values of  $H_{ec}$ ,  $s_{c,q/4}$  and  $s_{c,q}$ n = 0.04

$$\frac{\text{H}_{ec} \text{ vs } Q_{c,d} \text{ for various bottom widths, b}}{(\text{ES-173, 174, and 175})}$$

The critical discharge,  $Q_{c,d}$ , corresponding to the critical specific energy head,  $H_{ec}$ , and bottom width, b, is shown by ES-173, 174, and 175 when the side slopes are z=0, 2, and 3, respectively. The corresponding critical depth,  $d_{c,q}$ , is also given. Thus, for a broad-crested spillway containing a control section, the discharge, Q, is equal to the critical discharge,  $Q_{c,d}$ , corresponding to  $H_{ec}$ . When the spillway width, b, and the correspondence of  $H_p$  and  $H_{ec}$  (as given by ES-171) are known for a particular spillway, the correspondence of  $H_p$  and Q (i.e. spillway rating) is readily obtained.

The fundamental relations involving Hec, Qc,d, b, and z are

$$\frac{(Q_{c,d})^2}{g} = \frac{a_c^3}{T_c} = \frac{(b + zd_{c,q}) d_{c,q}}{(b + 2z d_{c,q})}^3$$
(4)

$$H_{ec} = d_{c,q} + \frac{v_c^2}{2g}$$
 (5)

$$H_{ec} = \frac{(3b + 5z d_{c,q})d_{c,q}}{2b + 4z d_{c,q}}$$
 (6)

For z = 0 the last relation reduces to

$$H_{ec} = \frac{3}{2} d_{c,q} \qquad \text{(when } z = 0\text{)}$$

Further,

$$H_{ec} = 0.4717 \left[ \frac{Q_{c,d}}{b} \right]^{2/3}$$
 (when  $z = 0$ ) (8)

$$\frac{Q_{\rm c,d}}{b} = 3.087 \text{ H}_{\rm ec}^{3/2}$$
 (when z = 0)

When  $z \neq 0$ , 2, or 3

The parameters, z and b, can have considerable effect on the value of  $Q_{c,d}$  corresponding to a particular critical specific energy head,  $H_{ec}$ .

When the critical discharge corresponding to a given  $H_{ec}$ , b, and z is to be determined, a direct solution may be made by solving Eq. (6) for  $d_{c,q}$  and then solving Eq. (4) for  $Q_{c,d}$ . The solution for  $H_{ec}$  corresponding to  $Q_{c,d}$ , z, and b is implicit. Both of these solutions can be simplified by an approximation. The approximation is; if two trapezoidal sections have equal critical specific energy heads, then the ratio of their corresponding critical discharges is approximately equal to the ratio of their average width at critical depth. When the side slopes of the trapezoidal section are equal, this approximation becomes,

$$\frac{Q_{C}}{Q_{C}^{\dagger}} = \frac{b + z d_{C}}{b^{\dagger} + z^{\dagger} d_{C}^{\dagger}} \qquad (\text{when } H_{eC} = H_{eC}^{\dagger})$$
 (10)

When the approximation is based on a rectangular section (z' = 0) of width b' = 100', obtain from Eq. (7)

$$d_{c}^{!} = \frac{2}{3} H_{ec}^{!} = \frac{2}{3} H_{ec}$$

and substituting into Eq. (10) in which the approximation  $d_c = d_c'$  is used, obtain

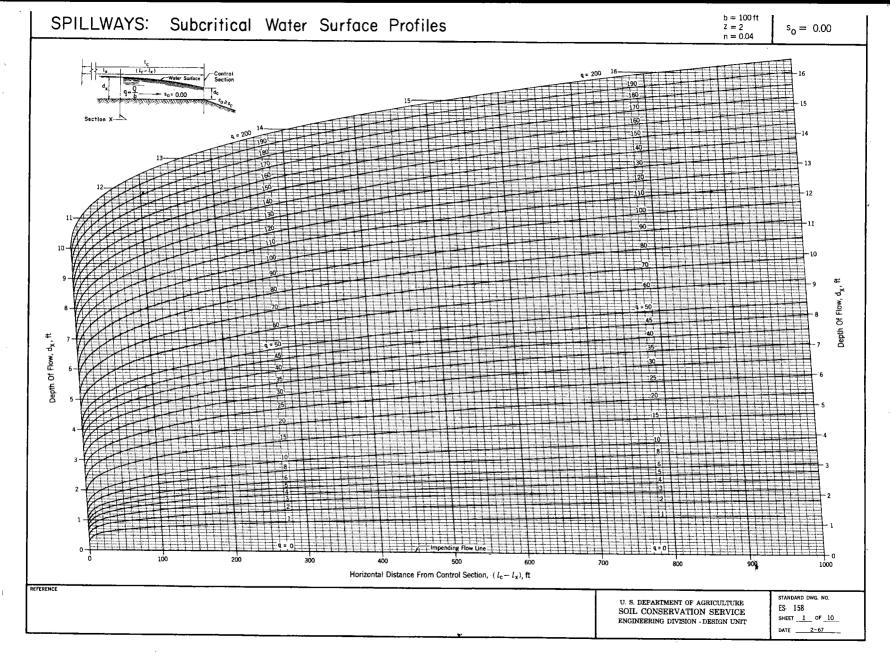
$$\frac{Q_{c}}{Q_{c}'} = \frac{b + z(\frac{2}{3} H_{ec})}{100} = \frac{1.5b + z H_{ec}}{150}$$
(11)

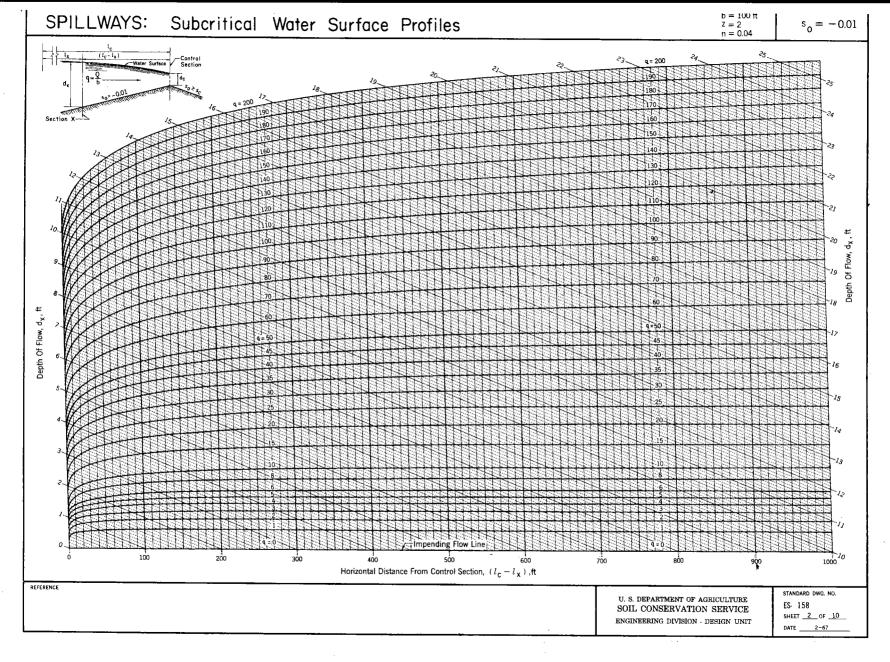
When the approximation is based on a rectangular section of width b'=100 ft, the error in the critical discharge,  $Q_{\rm c}$ , is readily obtained from ES-173, sheet 4, Figure 1.

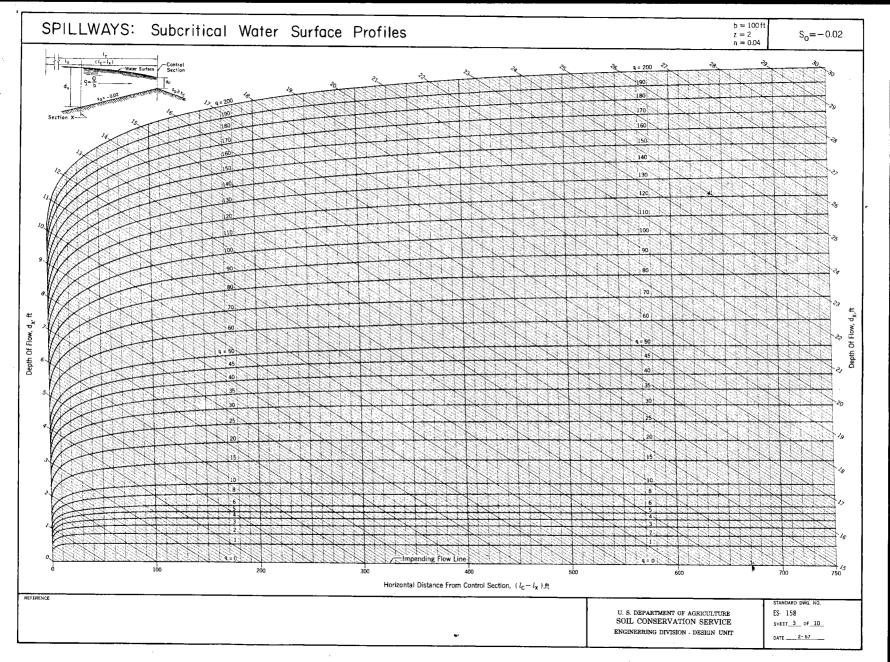
### Examples

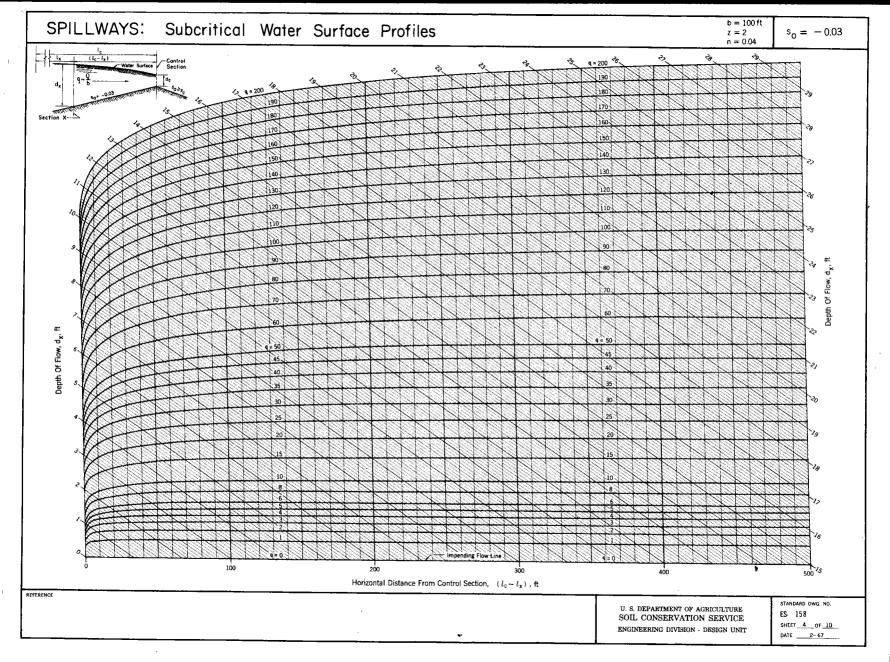
Examples are usually given with each ES-drawing in this technical release illustrating the use of the drawing. Two examples are given in ES-179 illustrating the interrelation of the ES-drawings.

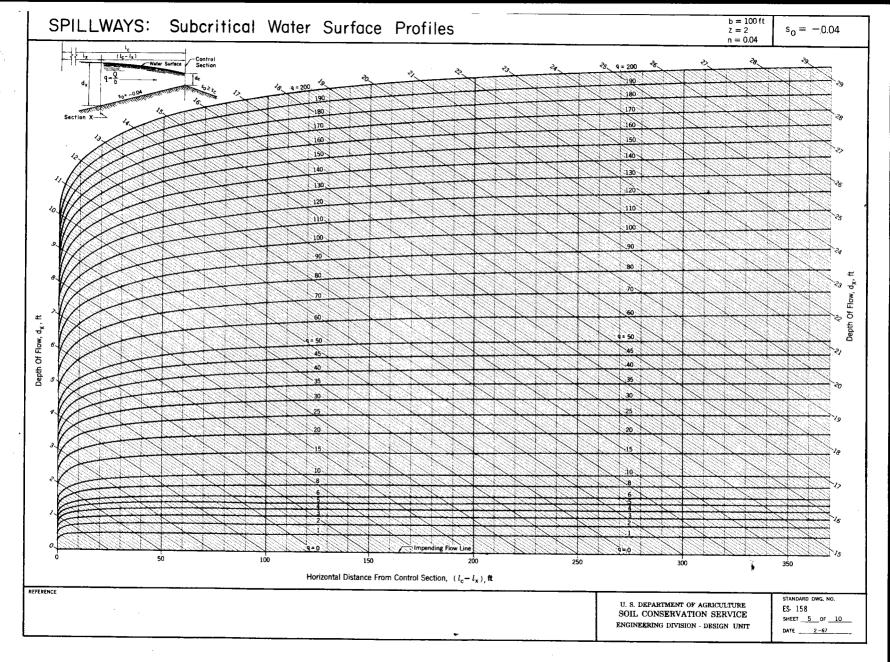
<sup>&</sup>lt;sup>1</sup>This approximation, in another form, was proposed by Mr. M. M. Culp, Chief, Design Branch, Engineering Division, SCS: See Tentative Technical Release No. 2.

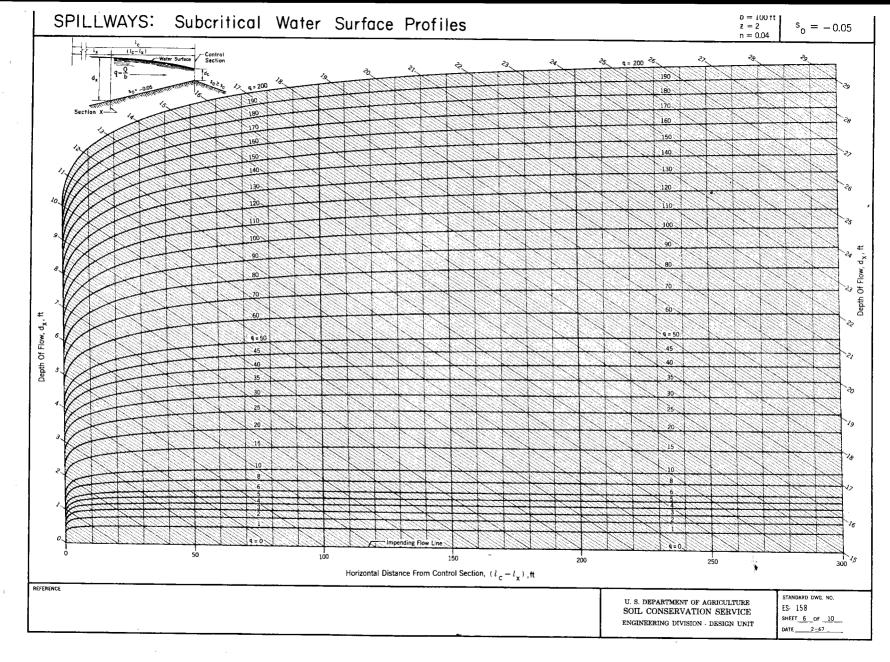


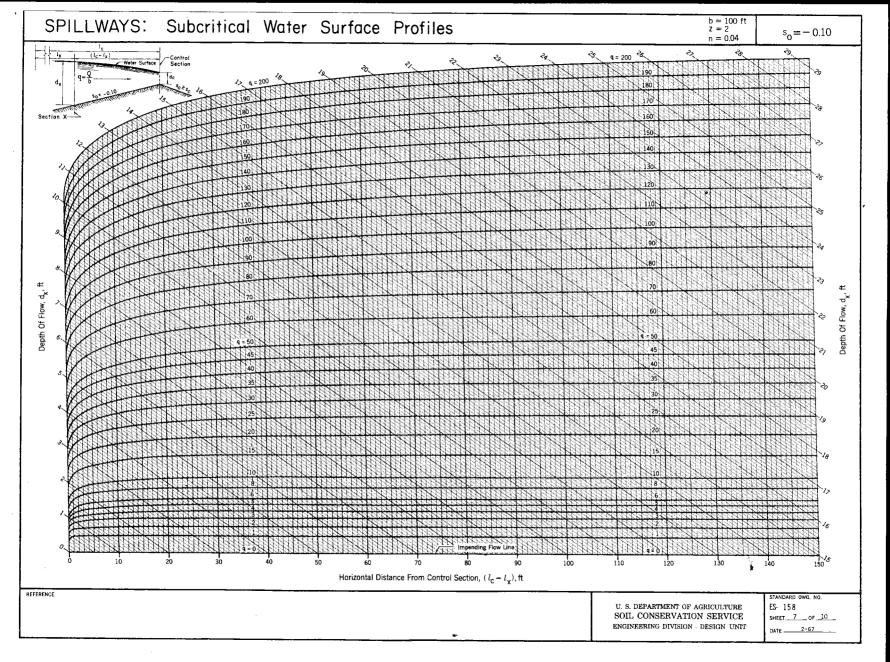


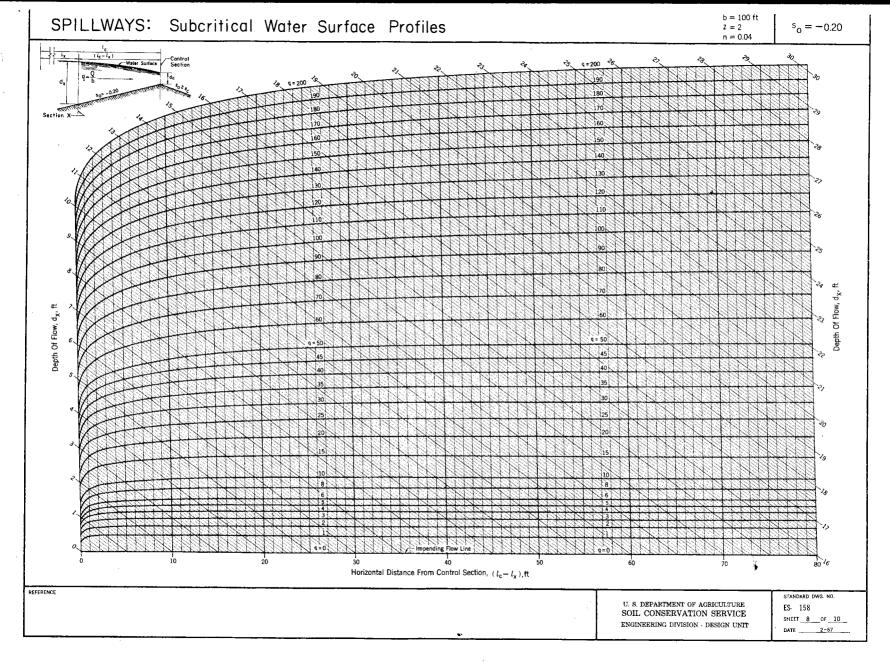












# SPILLWAYS: Subcritical Water Surface Profiles

#### NOMENCE ATTURE

 $d_{\mathbf{x}} \equiv depth \ of \ flow \ at section \ \mathbf{x}$ 

 $l_c \equiv$  station at the control section

 $\ell_x \equiv \text{station at section } x$ 

#### EXAMPLE 1

#### Given:

Emergency spillway bottom profile as shown in figure

Q = 3500 cfs

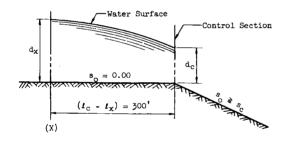
b = 100 ft

z = 2

n = 0.04

### Determine:

The depth of flow,  $d_x$ , at section x.



### Solution:

Use ES-158, sheet 1.

For  $(l_{c}-l_{x}) = 300$  ft and  $q = \frac{Q}{b} = \frac{3500}{100} = 35$  cfs/ft, read  $d_{x} = 5.67$  ft.

#### EXAMPLE 2

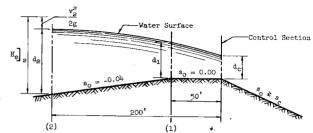
Emergency spillway bottom profile as shown in figure

Q = 5000 cfs

b = 100 ft

z = 2

n = 0.04



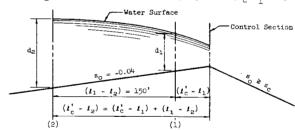
#### Determine:

I. The depth of flow,  $d_2$ , and II. The specific energy head,  $H_e$  , at section 2.

#### Solution:

I. Determine do

- A. Considering the 50 ft reach of s\_0 = 0.00 immediately upstream from the control section, use ES-158, sheet 1. For  $(l_c-l_1)$  = 50 ft and  $q = \frac{Q}{h} = \frac{5000}{100} = 50 \text{ cfs/ft, read d}_1 = 5.40 \text{ ft.}$
- B. Considering the 150 ft reach of  $s_0$  = -0.04, use ES-158, sheet 5. 1. For  $d_1$  = 5.40 ft and q = 50 cfs/ft, read  $(\ell_c^* \ell_1)$  = 9 ft.



- 2. For  $(\ell_0^* \ell_0) = 150 + 9 = 159$  ft and q = 50 cfs/ft, read  $d_{n} = 12.57$  ft.
- II. Determine  $H_e$

To obtain the velocity head,  $\frac{v_2^2}{2\sigma}$ , use ES-159, sheet 1.

For q = 50 cfs/ft and  $d_2 = 12.57$  ft, read  $\frac{v_2^2}{2\pi} = 0.16$  ft.

-Then  $H_{e}$ ] =  $d_2 + \frac{v_2^2}{2g} = 12.57 + 0.16 = 12.73 ft.$ 

# SPILLWAYS: Subcritical Water Surface Profiles

#### EXAMPLE 3

Given:

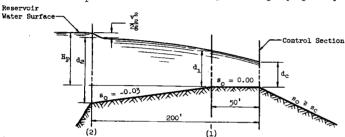
Emergency spillway bottom profile as shown in figure

z = 2

n = 0.04

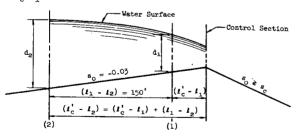
Determine:

The rating curve (HD vs Q relation) for the given emergency spillway.



#### Solution:

- I. Determine the depth of flow, da
  - A. Considering the 50 ft reach of  $s_0$  = 0.00 immediately upstream from the control section, use ES-158, sheet 1. For  $(\ell_c-\ell_1)$  = 50 ft and for various q values, read d, values.
  - B. Considering the 150 ft reach of  $s_0 = -0.03$ , use ES-158, sheet 4. 1. For the values of d, and the corresponding q, read values of (l;-l,).



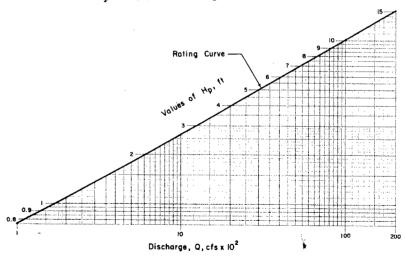
2. Then  $(l_C^! - l_2) = 150 + (l_C^! - l_1)$ . For the values of  $(l_C^! - l_2)$  and corresponding q, read d, values.

- II. Determine the energy head of the water in the reservoir above the spillway crest, Hp.
  - A. To obtain values of velocity head,  $\frac{v_2^2}{2a}$ , use ES-159.

For the values of  $d_2$  and corresponding q, read  $\frac{v_2^2}{2g}$  values. B. Then  $H_p = d_2 + \frac{v_2^2}{2g} - |s_0|(l_1 - l_2) = d_2 + \frac{v_2^2}{2g} - 0.03(150) = d_2 + \frac{v_2^2}{2g} - 4.50$ 

q	Q=qb	đ <sub>1</sub>	1'c-1 <sub>1</sub>	1'-1 <sub>2</sub>	d <sub>2</sub>	<u>v2</u> 2g	нр
cfs/ft	cfs	ft	ft	ft	ft	ft	ft
1	100	0.70	7	157	5.26		0.76
2	200	0.97	8	158	5.58		1.08
5	500	1.55	9	159	6.27	0.01	1.78
10	1,000	2.25	10	160	7.13	0.02	2.65
20	2,000	3.26	10	160	8.37	0.06	3.93
50	5,000	5.40	11	161	11.05	0.21	6.76
100	10,000	7.98	n	161	14.18	0.47	10.15
200	20,000	11.78	10	160	18.68	0.94	15.12

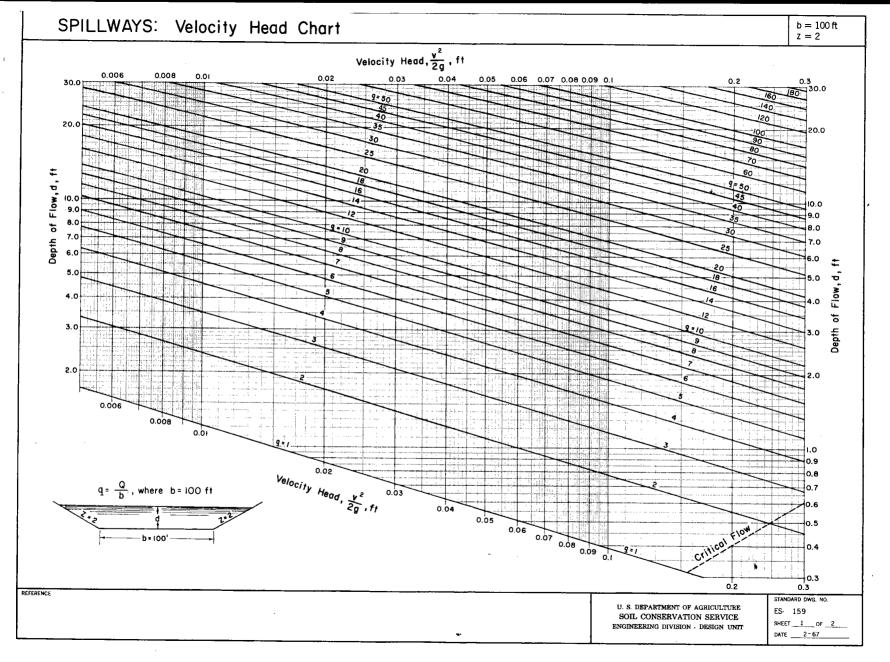
Knowing En and Q, plot the rating curve.

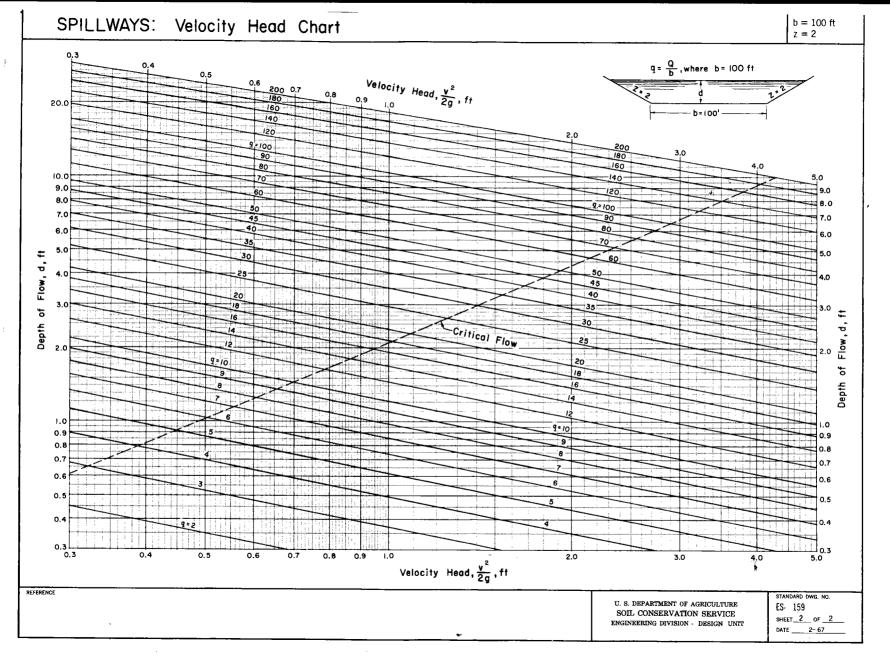


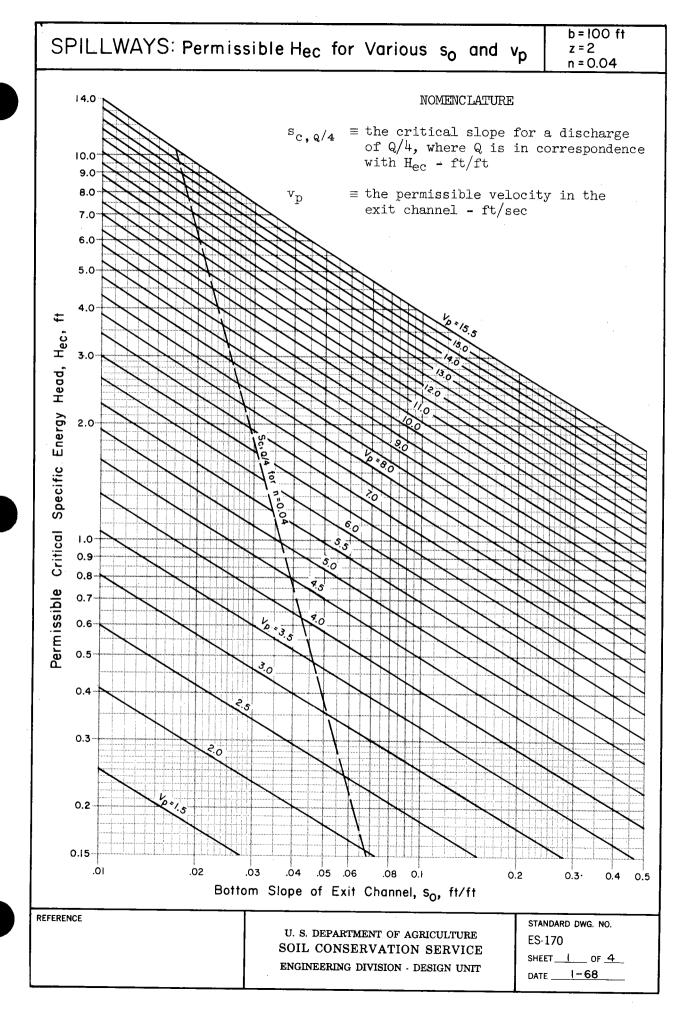
REFERENCE

U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT

STANDARD DWG, NO. ES 158 SHEET 10 OF 10 DATE \_\_ 4 - 67







# b = 100 ft SPILLWAYS: Permissible $H_{ec}$ for Various $s_o$ and $v_p$ z = 2n = 0.0210.0 NOMENCLATURE 9.0 $s_{c,Q/4}$ = the critical slope for a discharge of Q/4, where Q is in correspondence with Hec - ft/ft 7.0 $\equiv$ the permissible velocity in the 6,0 exit channel - ft/sec 5.0 The value of n in the block in the Note: upper right hand corner does not apply to the $s_{c,\,Q/4}$ -lines for 4.0 n = 0.03 and n = 0.04. Permissible Critical Specific Energy Head, Hec, ft 0.9 0.8 0.7 0.6 0.5 0.2 0.3 0.4 .04 .006 .008 .01 .004 Bottom Slope of Exit Channel, so, ft/ft STANDARD DWG. NO. REFERENCE U. S. DEPARTMENT OF AGRICULTURE ES-170 SOIL CONSERVATION SERVICE SHEET 2 OF 4 ENGINEERING DIVISION - DESIGN UNIT DATE 1-68

# SPILLWAYS: Examples-Permissible $H_{ec}$ for Various $s_0$ and $v_p$

#### EXAMPLE 1

### Given:

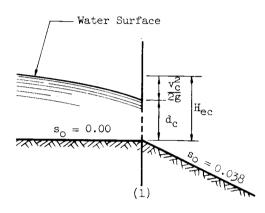
Emergency spillway bottom profile as shown in figure

z = 2

b = 100 ft

n = 0.04

 $v_p = 6.5 \text{ ft/sec}$ 



#### Determine:

- I. Permissible  $H_{ec}$
- II. If the exit channel bottom slope,  $s_{\rm O},$  is greater than or equal to  $s_{\rm C,\,Q/4}$

### Solution:

- I. Determine permissible  $H_{ec}$  Use ES-170, sheet 1. For n=0.04,  $v_p=6.5$  ft/sec, and  $s_0=0.038$ , read permissible  $H_{ec}=1.5$  ft.
- II. Determine if  $s_0 \ge s_0$ , Q/4

Use ES-170, sheet 1.

For  $H_{ec} = 1.5$  ft, read  $s_{c, q/4} = 0.032$ .

 $s_0 > s_{c,\,Q/4}$ ; therefore, a control section exists at section (1) for discharges in the interval Q/4 to Q.

SHEET 3 OF 4

STANDARD DWG. NO.

ES-170

# SPILLWAYS: Examples-Permissible Hec for Various so and vp

#### EXAMPLE 2

#### Given:

Emergency spillway bottom profile as shown in figure for Example 1 except that the exit channel bottom slope,  $s_0$ , is equal to 0.025

z = 2

b = 100 ft

 $v_p = 4.0 \text{ ft/sec}$ 

### Determine:

- I. Permissible  $H_{ec}$  when n = 0.02
- II. If  $s_0 \ge s_0$ , q/4, when the value of n in the exit channel is

A. 0.02

B. 0.03

#### Solution:

- I. Determine permissible  $H_{ec}$  Use ES-170, sheet 2. For n = 0.02,  $v_p$  = 4.0 ft/sec, and  $s_0$  = 0.025, read permissible  $H_{ec}$  = 0.41 ft.
- II. Determine if  $s_0 \ge s_c, q/4$ 
  - A. When n = 0.02 Use ES-170, sheet 2. For n = 0.02 and  $H_{ec}$  = 0.41 ft, read  $s_0$  = 0.0122 =  $s_c$ ,  $\varrho/4$ . Thus, the exit channel bottom slope,  $s_0$ , is gr

Thus, the exit channel bottom slope,  $s_{\rm O}$ , is greater than  ${}^{\rm S}{}_{\rm C}$ ,  ${}^{\rm Q}/4$ .

B. When n=0.03Use ES-170, sheet 2. For n=0.03 and  $H_{ec}=0.41$  ft, read  $s_0=0.0275=s_c, q/4$ . Thus, the exit channel bottom slope,  $s_0$ , is smaller than

Therefore, if the value of Manning's n is altered, say by vegetative growth, from a value of 0.02 to 0.03, Section (1) is no longer a control section for all discharges in the interval Q/4 to Q.

REFERENCE

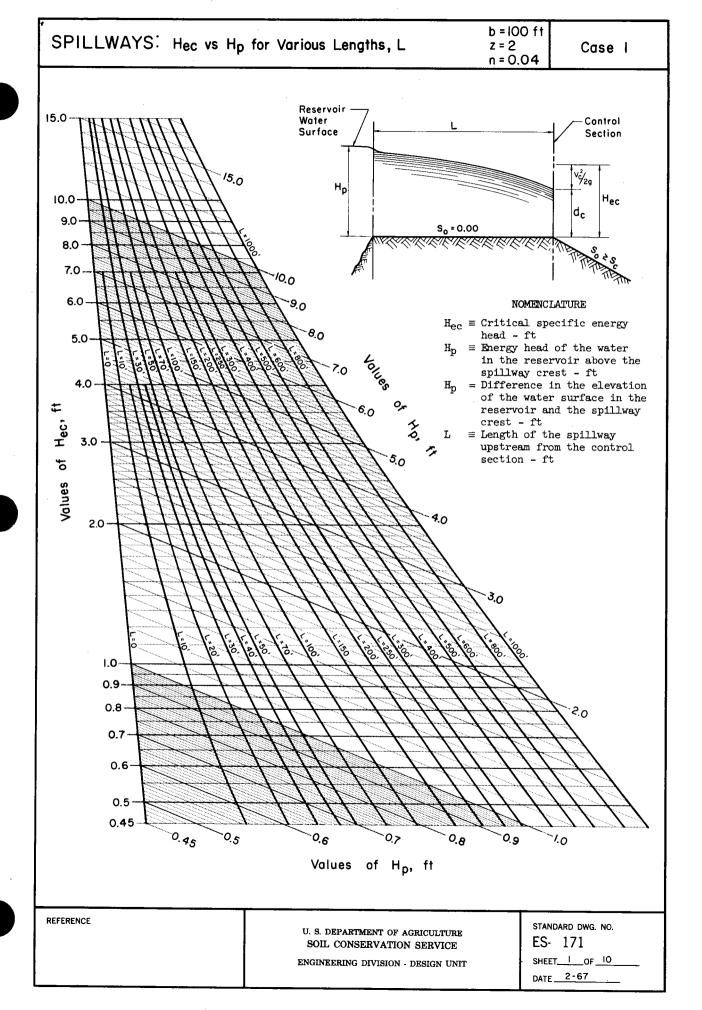
U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE

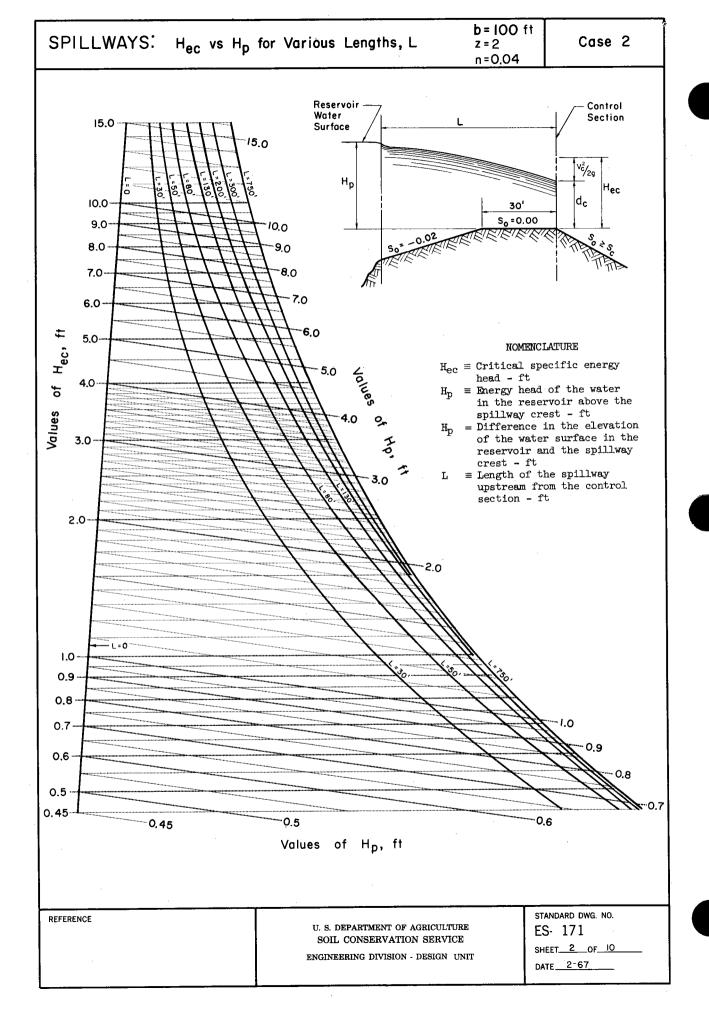
ES 170 SHEET 4 OF 4

DATE 2-68

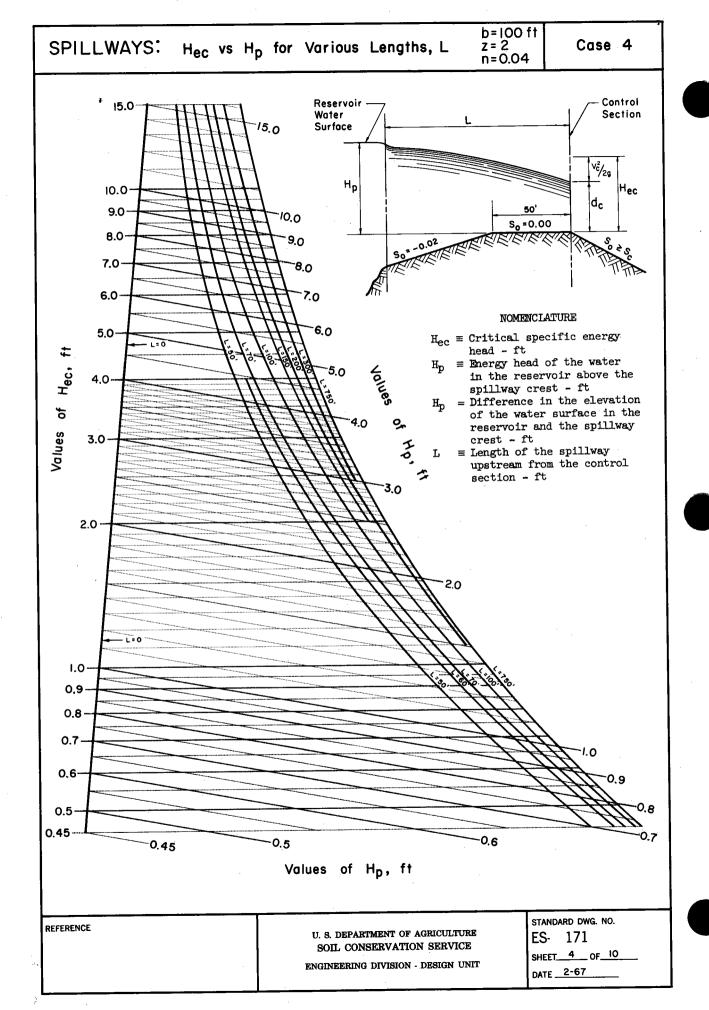
STANDARD DWG. NO.

ENGINEERING DIVISION - DESIGN UNIT

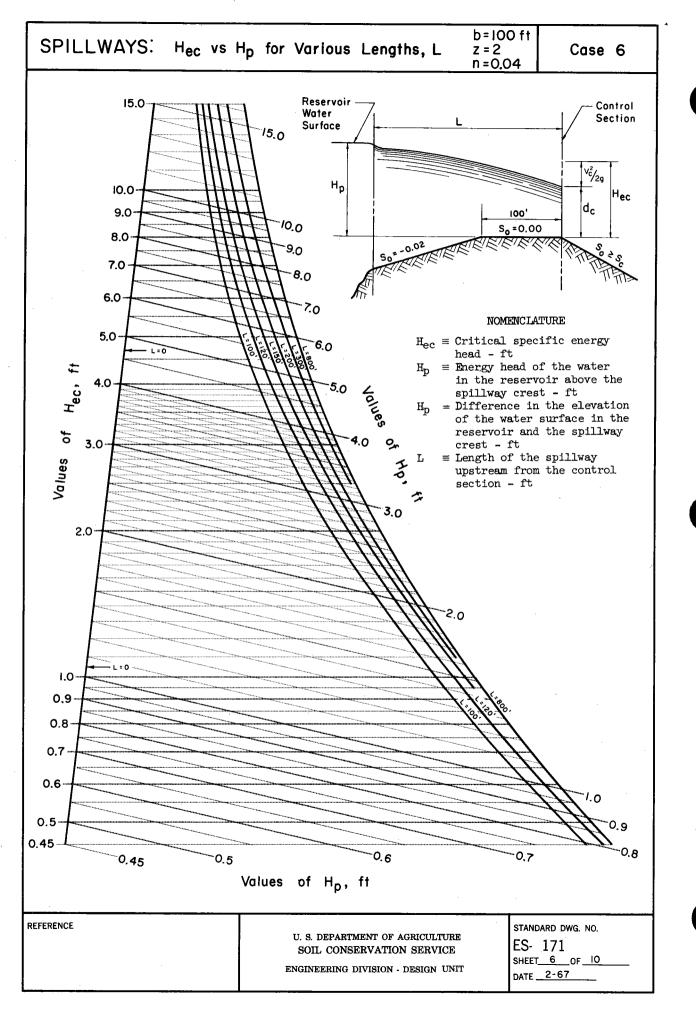


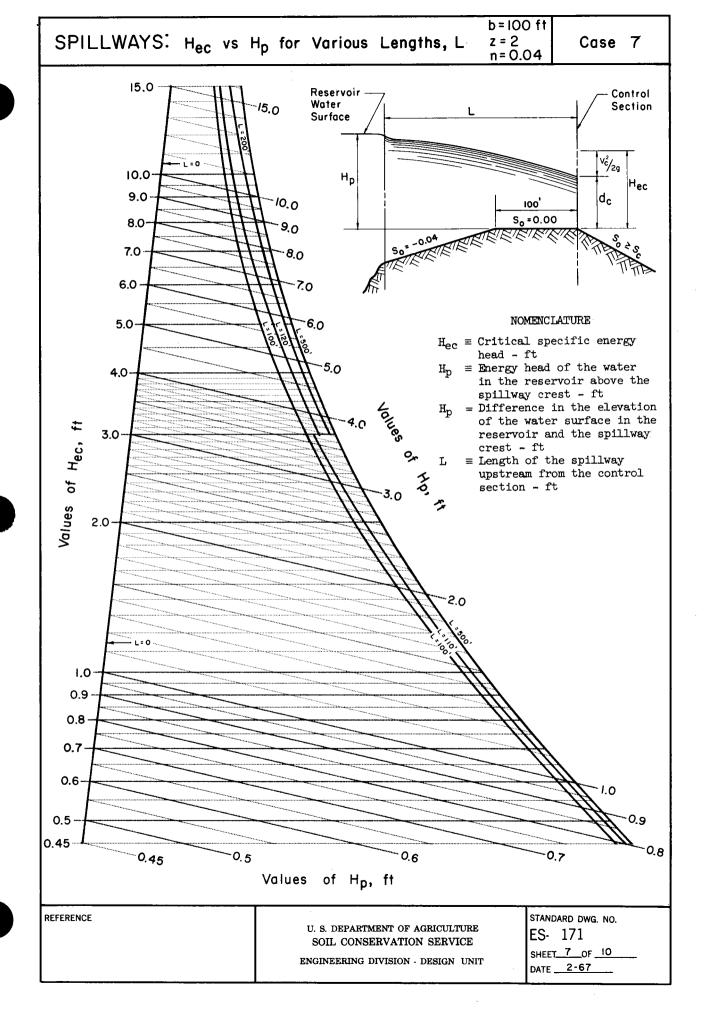


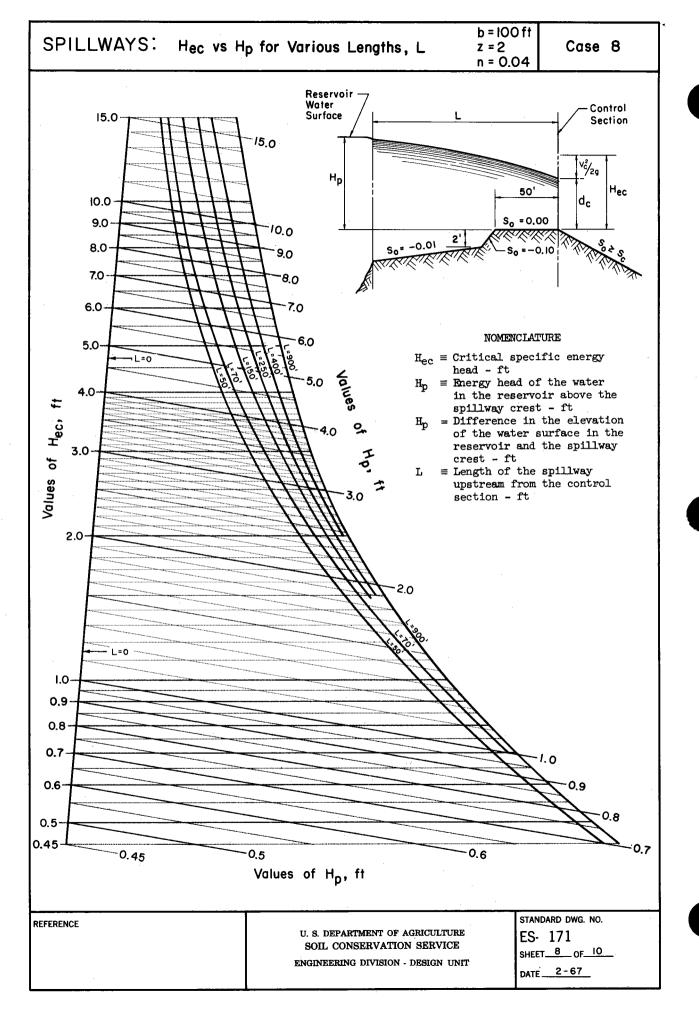
b = 100 ft SPILLWAYS: H<sub>ec</sub> vs H<sub>D</sub> for Various Lengths, L Case 3 z = 2n = 0.04Reservoir 15.0 Control Water Section 15.0 Surface  $H_{\mathbf{p}}$ 10.0 Hec 10.0 9.0 S<sub>0</sub> = 0.00 9.0 8.0 8.0 7.0 7.0 6.0 6.0 5.0 NOMENCLATURE  $\mathbf{H}_{ec} \equiv \mathbf{Critical}$  specific energy 5.0 head - ft Values of H<sub>ec</sub>, ft 4.0 ≡ Energy head of the water in the reservoir above the spillway crest - ft = Difference in the elevation of the water surface in the 3.0 reservoir and the spillway crest - ft ≡ Length of the spillway upstream from the control section - ft 2.0 1.0 0.9 0.8 0.7 0.6 0.5 0.45 -0.5 0.45 0.6 Values of H<sub>p</sub>, ft REFERENCE STANDARD DWG. NO. U. S. DEPARTMENT OF AGRICULTURE ES- 171 SOIL CONSERVATION SERVICE SHEET 3 OF 10 ENGINEERING DIVISION - DESIGN UNIT DATE 2-67

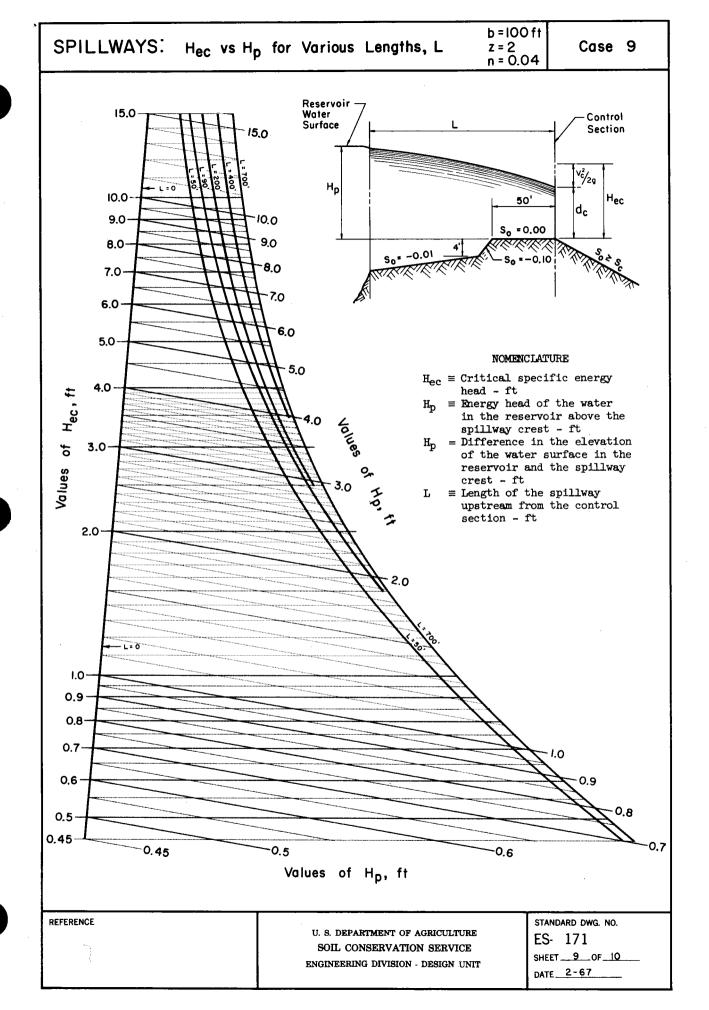


b=100 ft SPILLWAYS: Hec vs Hp for Various Lengths, L Case 5 z = 2n = 0.04Reservoir 15.0 Control Water Section Surface  $H_{D}$ 10.0 Hec dc 10.0 9.0 s<sub>o</sub> = 0.00 9.0 8.0 8.0 7.0-7.0 6.0 6.0 NOMENCLATURE 5.0- $H_{ec} \equiv Critical$  specific energy head - ft Values of H<sub>ec</sub>, ft 5.0  $H_D \equiv Energy head of the water$ 4.0 in the reservoir above the spillway crest - ft = Difference in the elevation of the water surface in the reservoir and the spillway 3.0 crest - ft ■ Length of the spillway upstream from the control. section - ft 2.0 2.0 1.0 0.9 0.8 0.7 0.6-0.5 0.45 0.45 0.5 Values of H<sub>D</sub>, ft STANDARD DWG. NO. REFERENCE U. S. DEPARTMENT OF AGRICULTURE ES- 171 SOIL CONSERVATION SERVICE SHEET 5 OF 10 **ENGINEERING DIVISION - DESIGN UNIT** DATE 2-67









# SPILLWAYS: Example-Hec vs Hp for Various Lengths, L

#### EXAMPLE

#### Given:

Emergency spillway bottom profile as shown in figure

$$b = 100 \text{ ft}$$

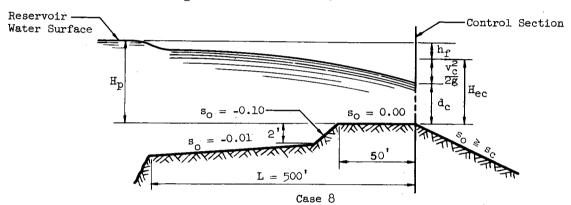
$$z = 2$$

$$n = 0.04$$

$$H_{ec} = 3.1 \text{ ft}$$

### Determine:

- 1. Hp
- 2. Friction head loss, h<sub>f</sub>, in the distance, L



#### Solution:

- 1. Determine  $H_p$  Use ES-171, sheet 8. For  $H_{ec}$  = 3.1 ft and L = 500 ft, read  $H_p$  = 3.66 ft.
- 2. Compute  $h_f$  $h_f = H_0 - H_{ec} = 3.66 - 3.10 = 0.56 \text{ ft}$

#### NOTE:

The  $H_p$  corresponding to an  $H_{ec}$  remains nearly constant regardless of the bottom width (where 25'  $\leq$  b  $\leq$  400') and side slope of the emergency spill-way.

See ES-176 for the effect of n, z, or b on  $\mathbf{H}_{\mathrm{p}}.$ 

REFERENCE

U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE

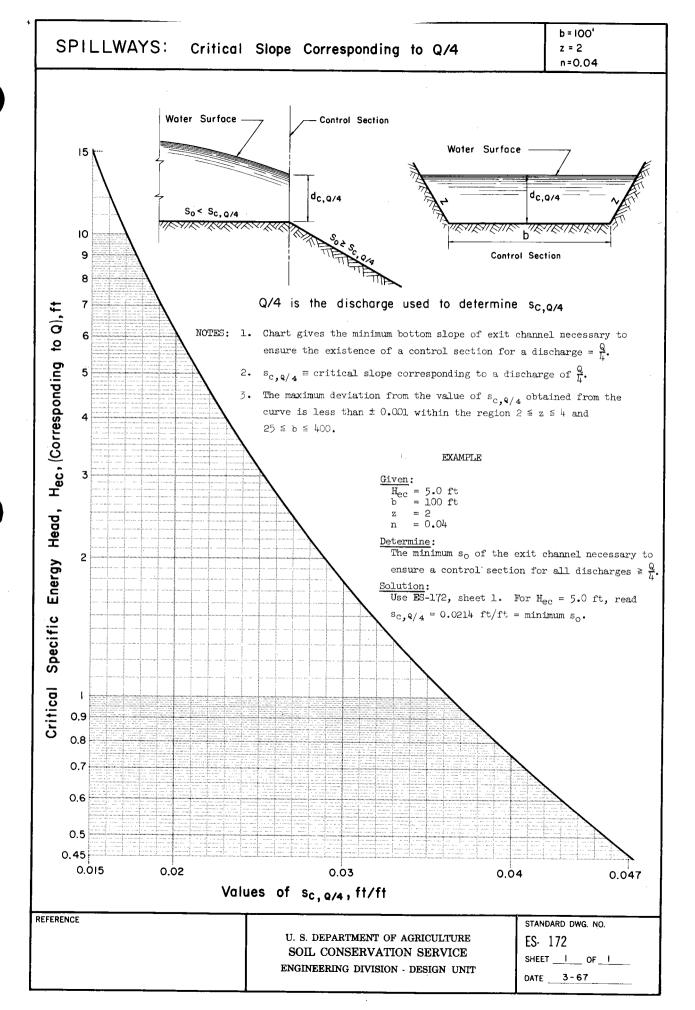
ENGINEERING DIVISION - DESIGN UNIT

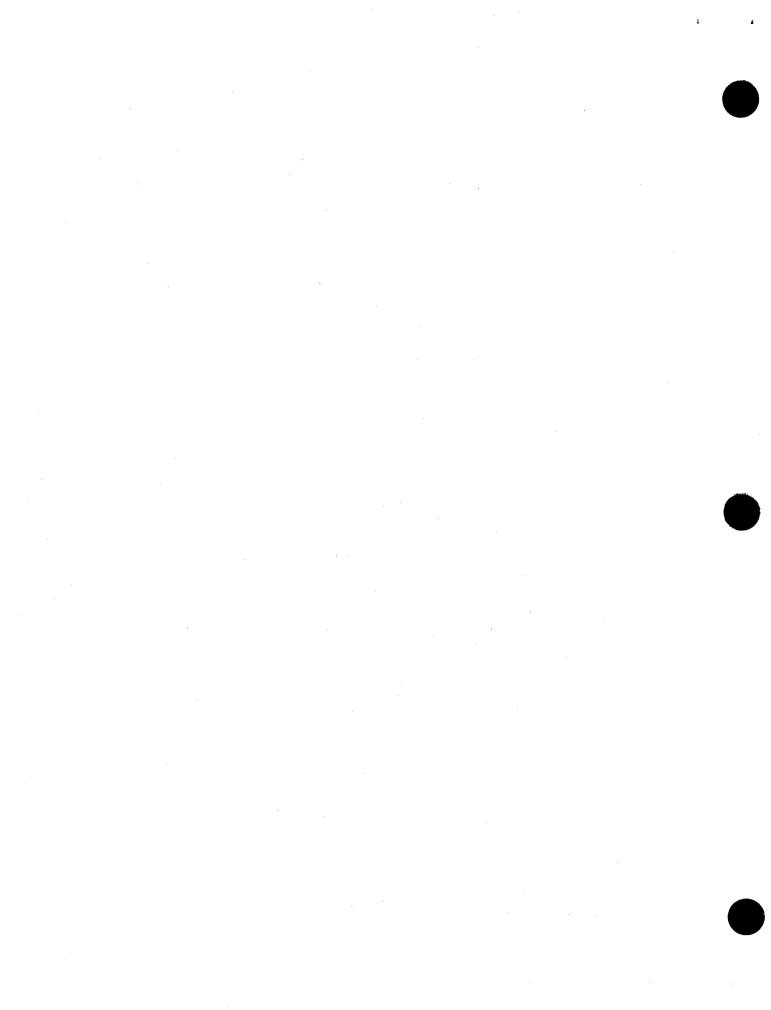
STANDARD DWG. NO.

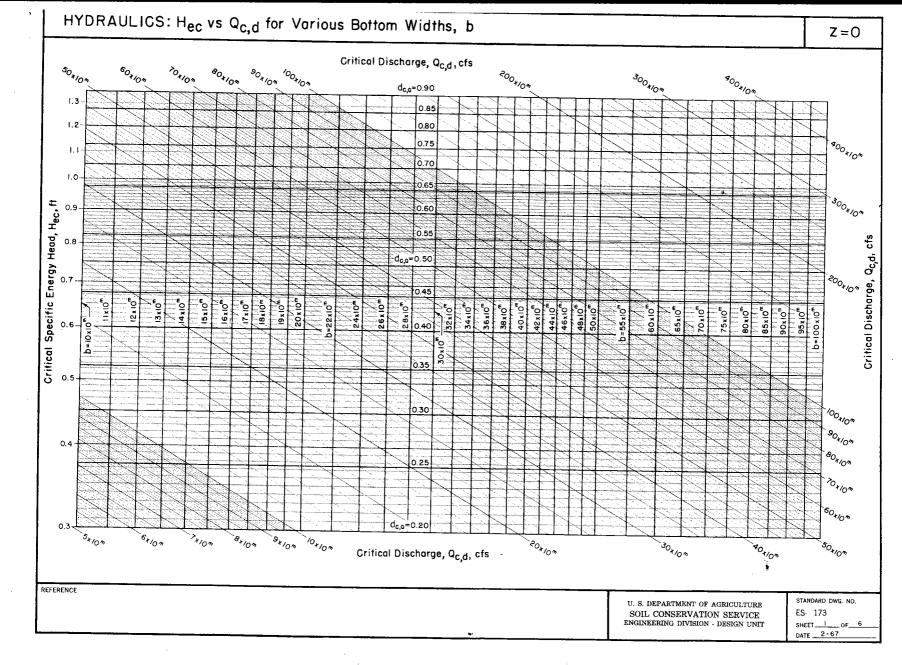
ES- 171

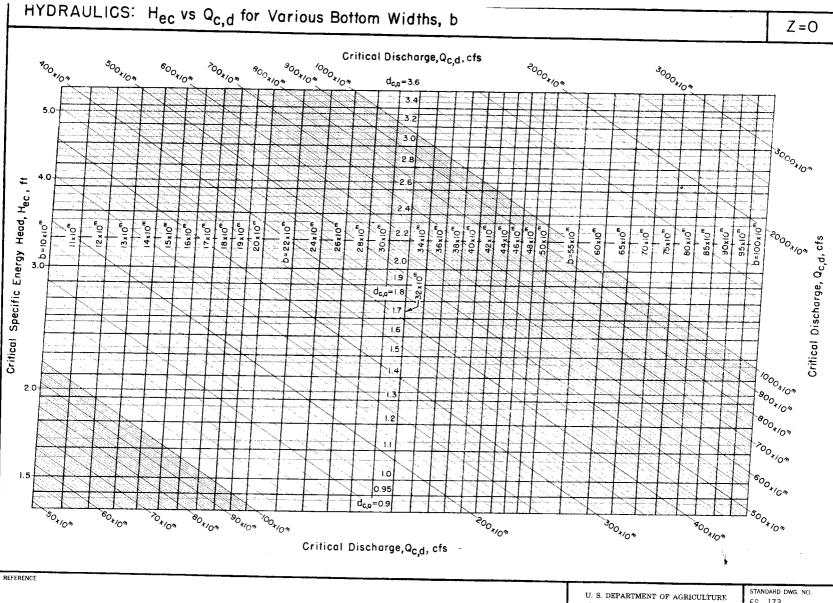
SHEET <u>10</u> of <u>10</u>

DATE 6 - 67



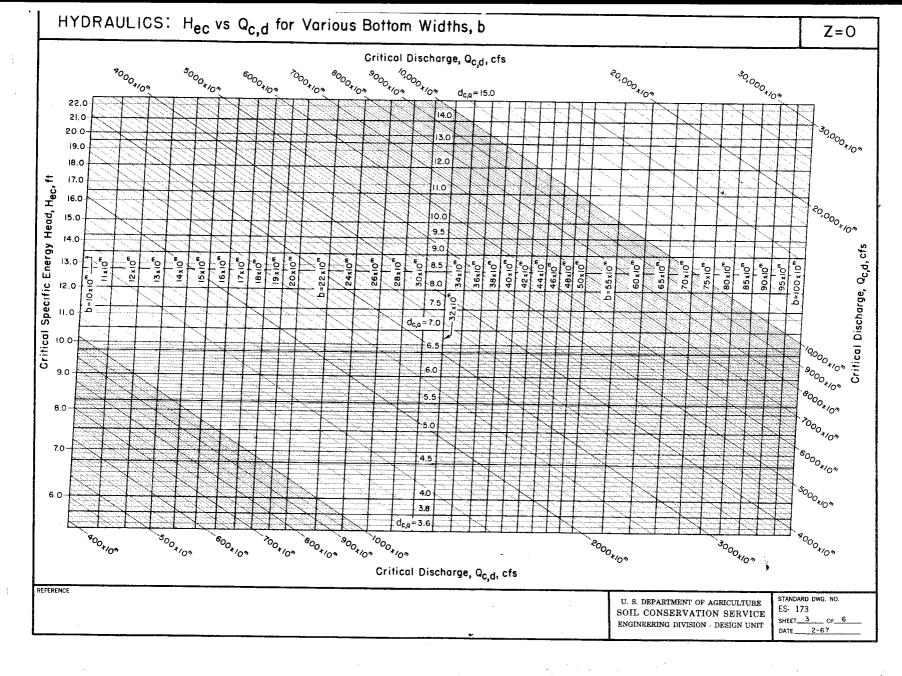






U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION DESIGN UNIT ES- 173

SHEET\_ 2\_\_\_OF\_ 6\_\_\_
DATE \_\_\_2-67



An approximate relation of critical discharges for a trapezoidal channel and for a channel of bottom width = 100 ft and side slope = 0 having the same  $\rm H_{ec}$  as the trapezoidal channel is

$$\frac{Q_{c}}{Q_{c}^{1}} = \frac{1.5b + zH_{ec}}{150}$$

Equation 1

where:  $Q_{\rm c}^{\star}$   $\equiv$  the critical discharge for a channel of bottom width = 100 ft and side slope = 0.

 $\rm H_{ec}$   $\equiv$  the critical specific energy head corresponding to the critical discharges,  $\rm Q_c^{*}$  and  $\rm Q_c^{*}$ 

- A. When Q is to be determined,
  - ${\sf Q}_{\sf C}$   $\equiv$  the first approximation of the critical discharge, as obtained from Equation 1, for a channel of bottom width, b, and side slope, z.
- B. When b is to be determined.
  - b  $\equiv$  the first approximation of the bottom width, as obtained from Equation 1, associated with a critical discharge,  $Q_c$ , and side slope, z.

When a second and closer approximation of critical discharge is required, the following equation may be used.

$$Q_{c}^{"} = \frac{Q_{c}}{1 - \frac{q_{c}}{2} \text{Error}}$$

Equation 2

where:  $Q_C^{\pi}$  = the second and closer approximation of the critical discharge for a channel of bottom width, b, and side slope, z.

When a second and closer approximation of bottom width is required, the following equation may be used.

$$b'' = \frac{b}{1 - \frac{\% \text{ Error}}{100}}$$

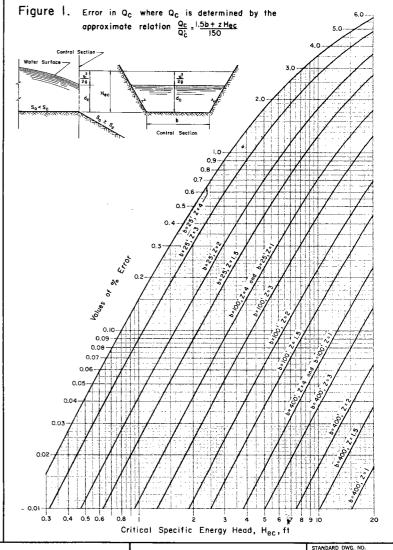
Equation 3

where: b"  $\equiv$  the second and closer approximation of the bottom width associated with a critical discharge,  $Q_C$ , and side slope, z.

The value of % Error may be obtained from Figure 1 or from the approximate relation

# Error = 2.27 
$$\left[\frac{zH_{ec}}{b}\right]^{1.1} + \left[\log_{10}\left(\frac{b}{zH_{ec}}\right)\right] \left[0.59 - 0.136 \log_{10}\left(\frac{b}{zH_{ec}}\right)\right]$$

Equation 4



REFERENCE

U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT ES- 173

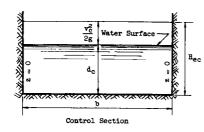
SHEET 4 OF 6

DATE 4-67

#### EXAMPLE 1

Given:

$$\frac{H_{ec}}{z} = 8.0 \text{ ft}$$



Determine:

I. Critical depth, dc

II. Bottom width, b, where  $Q_{c,d} = 200$ , 2,000, and 20,000 cfs

Solution

Use ES-173, sheet 3.

I. Determine  $d_c$ For  $H_{ec} = 8.0$  ft, read  $d_c = 5.3$  ft.

II. Determine b

- A. Where  $Q_{c,d} = 200 = 2,000 \times 10^{m}$ ; m = -1For  $H_{ec} = 8.0$  ft and  $Q_{c,d} = 200$ , read  $b = 28.5 \times 10^{m} = 28.5 \times 10^{-1} = 2.85$  ft.
- B. Where  $Q_{c,d} = 2,000 = 2,000 \times 10^{m}$ ; m = 0Then  $b = 28.5 \times 10^{m} = 28.5 \times 10^{0} = 28.5$  ft
- C. Where  $Q_{c,d} = 20,000 = 2,000 \times 10^{m}$ ; m = 1 Then b = 28.5 x  $10^{m} = 28.5 \times 10^{1} = 285$  ft

#### EXAMPLE 2

Given:

A trapezoidal channel

$$z = 4$$
  
 $H_{ec} = 4.5 \text{ ft}$   
 $Q_{ec} = 4400 \text{ cfs}$ 

Determine:

- The first approximation of the bottom width, b, by the use of Equation 1.
- II. The second approximation of the bottom width, b", by the use of Figure 1.

Solution:

I. Determine b

- A. Use ES-173, sheet 2. For  $H_{\rm ec}$  = 4.5 ft and b = 100 ft, read  $Q_{\rm c}^{\rm t}$  = 2950 cfs.
- B. From Equation 1,

$$b = \frac{100(Q_c)}{Q_c'} - \frac{zH_{ec}}{1.5}$$

$$b = \frac{100(4400)}{2950} - \frac{(4)(4.5)}{1.5}$$

$$b = 149 - 12 = 137 \text{ ft}$$

II. Determine b"

A. Use Figure 1.

For  $H_{ec} = 4.5$  ft, b = 137 ft, and z = 4, estimate % Error = 0.1.

B. Then substituting into Equation 3

$$b'' = \frac{b}{1 - \frac{6 \text{ Error}}{100}} = \frac{137}{1 - \frac{0.1}{100}} = 137 \text{ ft}$$

## $\label{eq:hydraulics} \mbox{HYDRAULICS: Examples - $H_{ec}$ vs $Q_{c,d}$ for Various Bottom Widths, $b$ and Side Slopes, $z$ }$

#### EXAMPLE 3

Given:
A traj

A trapezoidal channel b = 50 ft

$$b = 50 \text{ ft}$$
  
 $z = 2.5$   
 $H_{ec} = 7.5 \text{ ft}$ 

Determine:

I. The first approximation of the corresponding critical discharge, 
$$Q_{\rm c}$$
, by the use of Equation 1.

use of Equation 1.

II. The second approximation of the corresponding critical discharge, 
$$Q_c^{"}$$
,

A. By the use of Figure 1

Solution:

I. Determine  $Q_c$ Use ES-175, sheet 3. For  $H_{ec}$  = 7.5 ft and b = 100 ft, read  $Q_c^1$  = 6340 cfs.

From Equation 1
$$Q_{c} = \frac{1.5b + zH_{ec}}{150} Q_{c}$$

Substituting

$$Q_{c} = \frac{1.5(50) + 2.5(7.5)}{150}$$
 6340 = 3963 cfs

#### II. Determine Q"

A. By use of Figure 1

Use Figure 1 to prepare a plot of b vs % Error For H<sub>ec</sub> = 7.5 ft,
 b = 25 ft, and z = 2 and 3;
 b = 100 ft, and z = 2 and 3; and
 b = 400 ft, and z = 2 and 3,
 read % Error values.

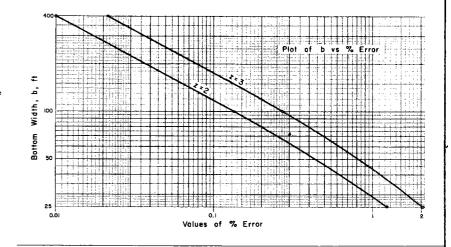
Plot b vs % Error with z = 2 and z = 3 lines.

Use plot of b vs \$ Error to obtain \$ Error for z = 2.5 and b = 50 ft.
 For b = 50 ft and z = 2, read \$ Error = 0.44.

For b = 50 ft and z = 3, read % Error = 0.44. Then for b = 50 ft and z = 2.5, % Error =  $\frac{0.44 + 0.82}{2} = 0.63$ .

3. Then substituting into Equation 2

$$Q_{c}^{"} = \frac{Q_{c}}{1 - \frac{Q_{c}}{1000}} = \frac{3963}{1 - \frac{0.63}{100}} = 3988 \text{ cfs}$$



B. By use of Equation 4

1. Substituting into Equation 4

\$ Error = 2.27 
$$\left[\frac{zH_{ec}}{b}\right]^{1.1} + \left[Log_{10}\left(\frac{b}{zH_{ec}}\right)\right]^{0.59} - 0.136 Log_{10}\left(\frac{b}{zH_{ec}}\right)$$

$$= 2.27 \left[\frac{2.5(7.5)}{50}\right]^{1.1} + \left[Log_{10}\left(\frac{50}{2.5(7.5)}\right)\right]^{0.59} - 0.136 Log_{10}\left(\frac{50}{2.5(7.5)}\right)$$

$$= 2.27 \left[0.375\right]^{1.1} + \left[Log_{10} 2.667\right]^{0.59} - 0.136 Log_{10} 2.667$$

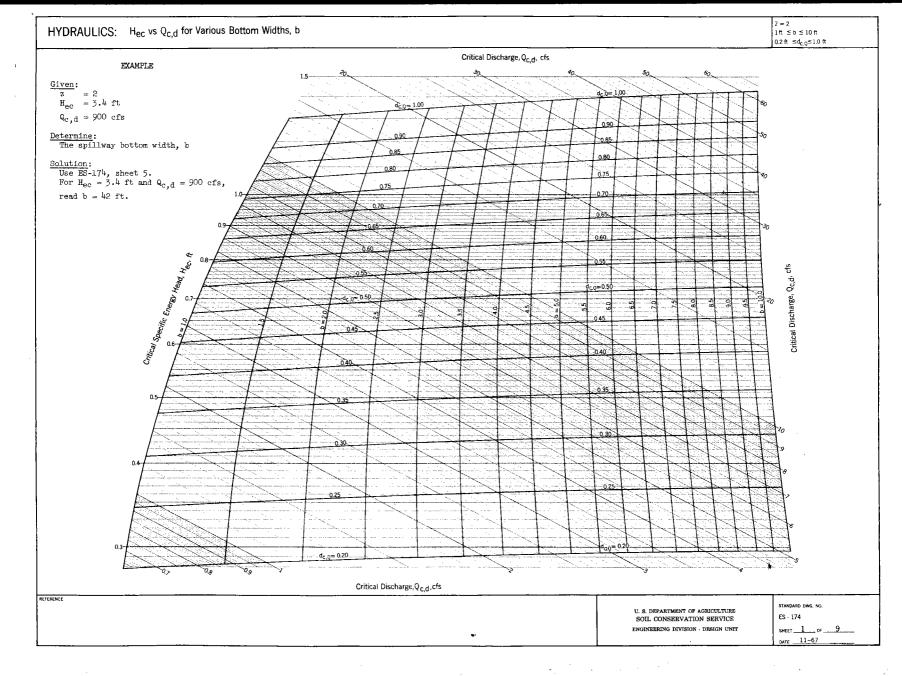
$$= 2.27 \left[0.375\right]^{1.1} + \left[0.42e\right]^{0.59} - 0.058$$

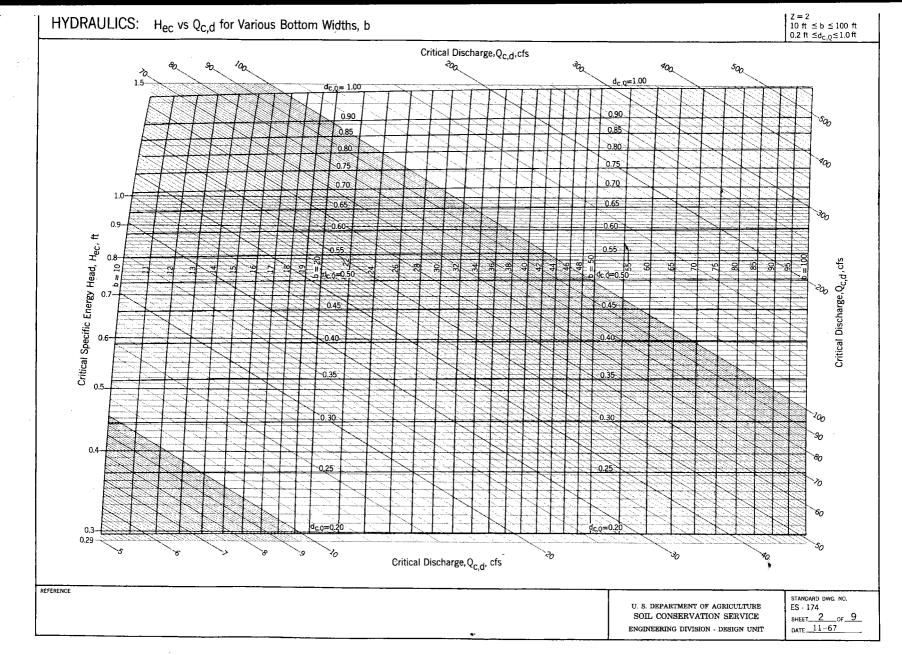
2. Then substituting into Equation 2

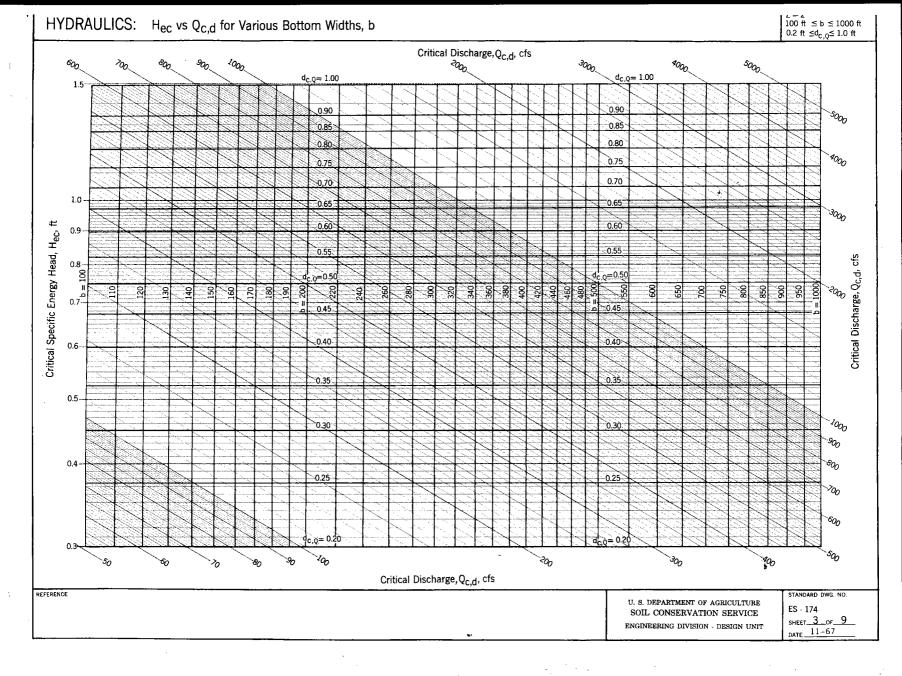
$$Q_c'' = \frac{Q_c}{1 - \frac{9}{100}} = \frac{3965}{1 - \frac{0.618}{100}} = 3988 \text{ cfs}$$

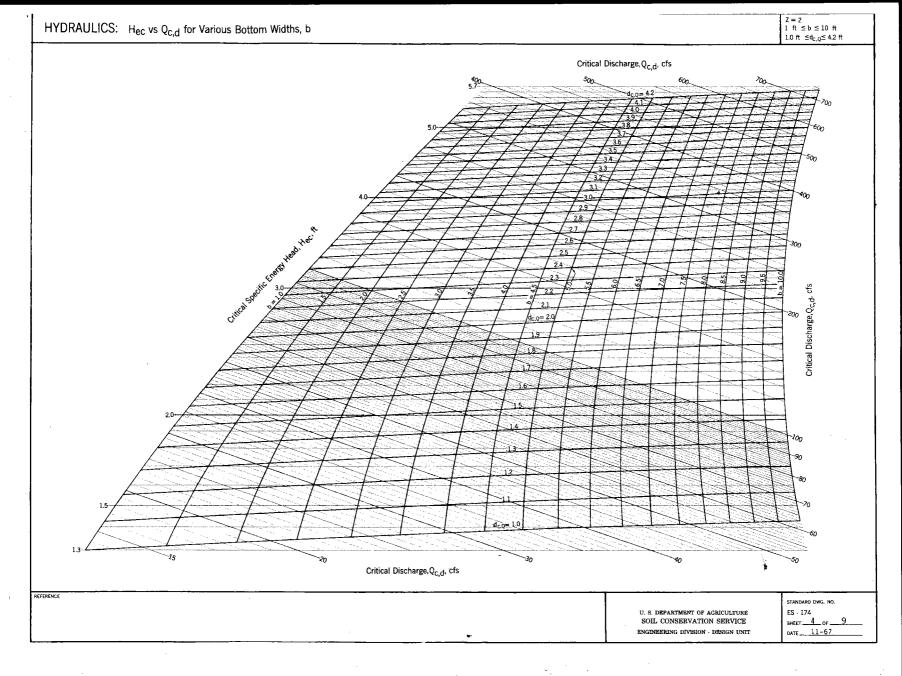
REFERENCE

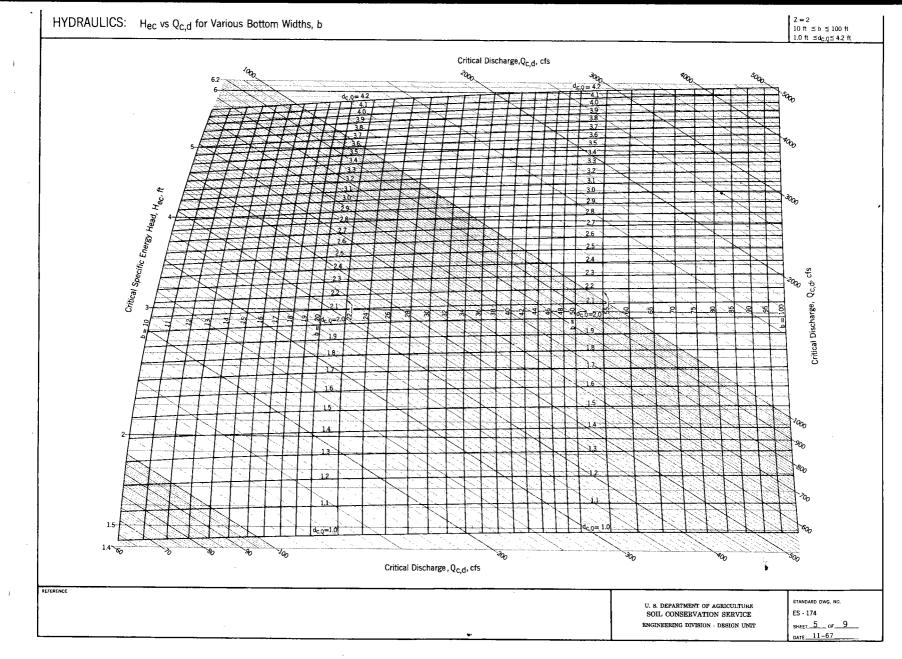
U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT STANDARD DWG. NO.
ES- 173
SHEET 6 OF 6
DATE 6-67

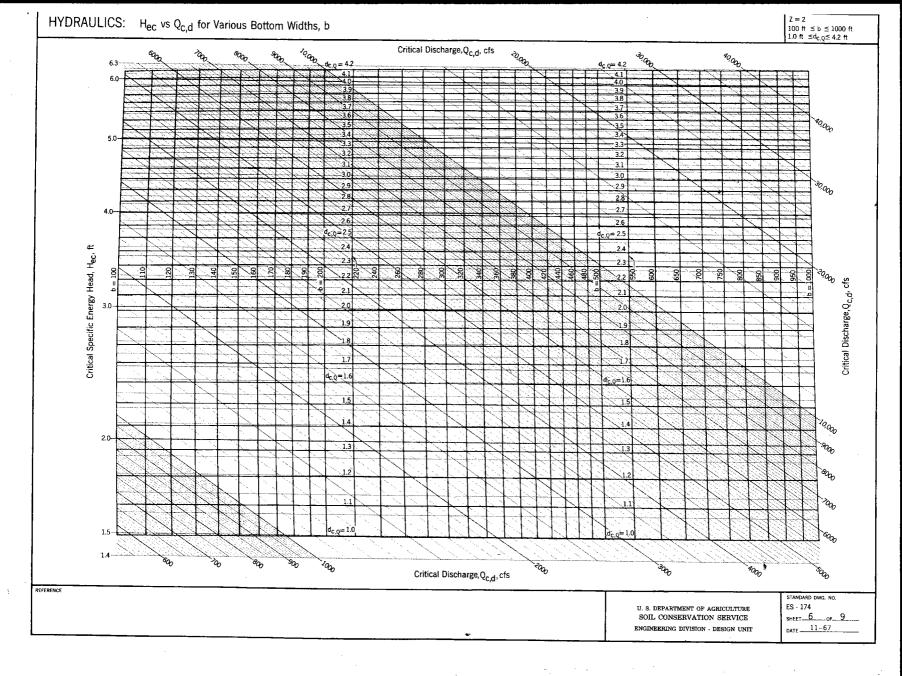


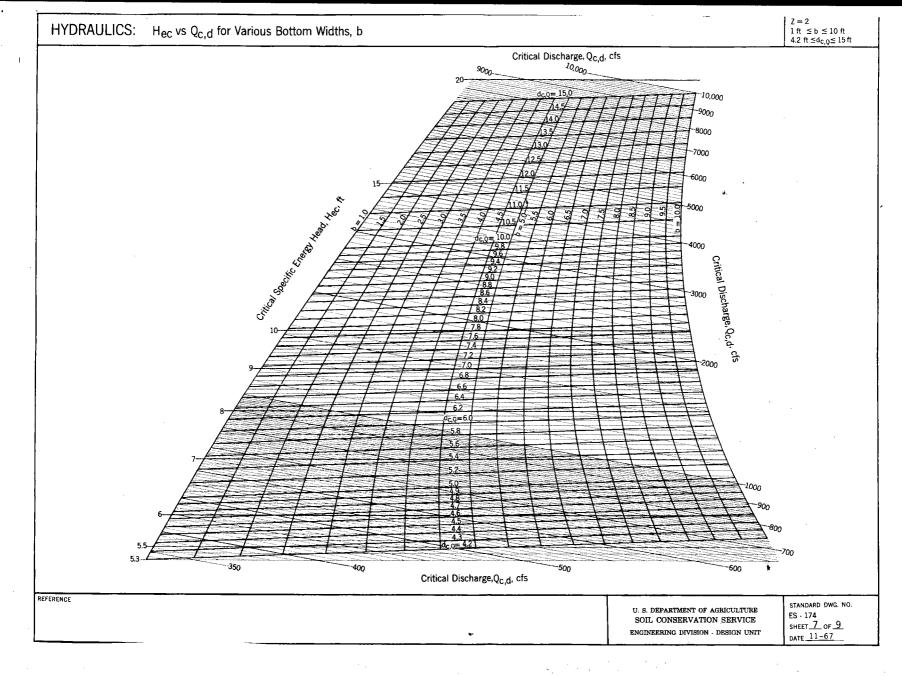


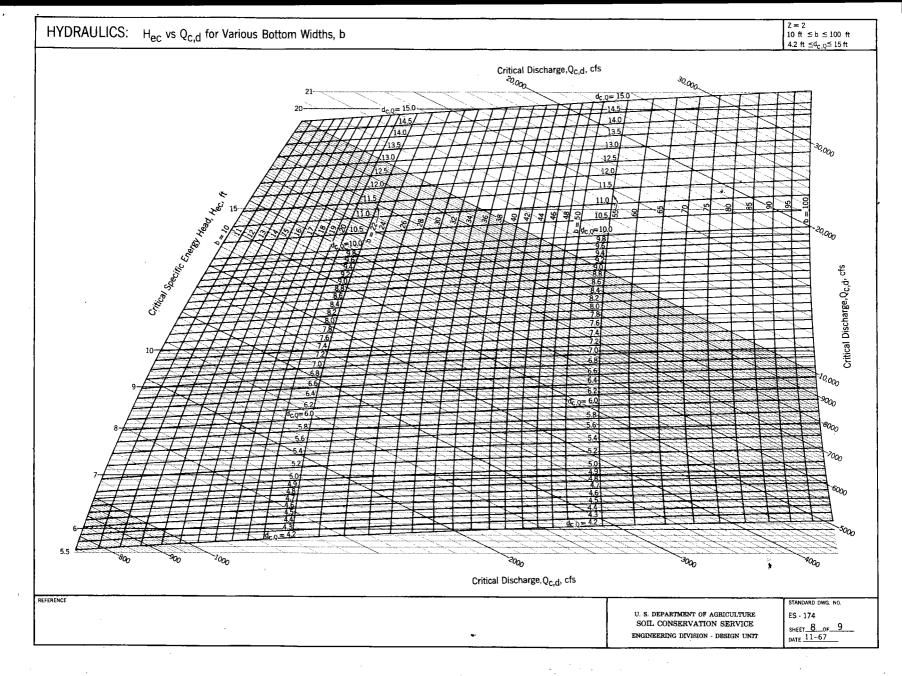


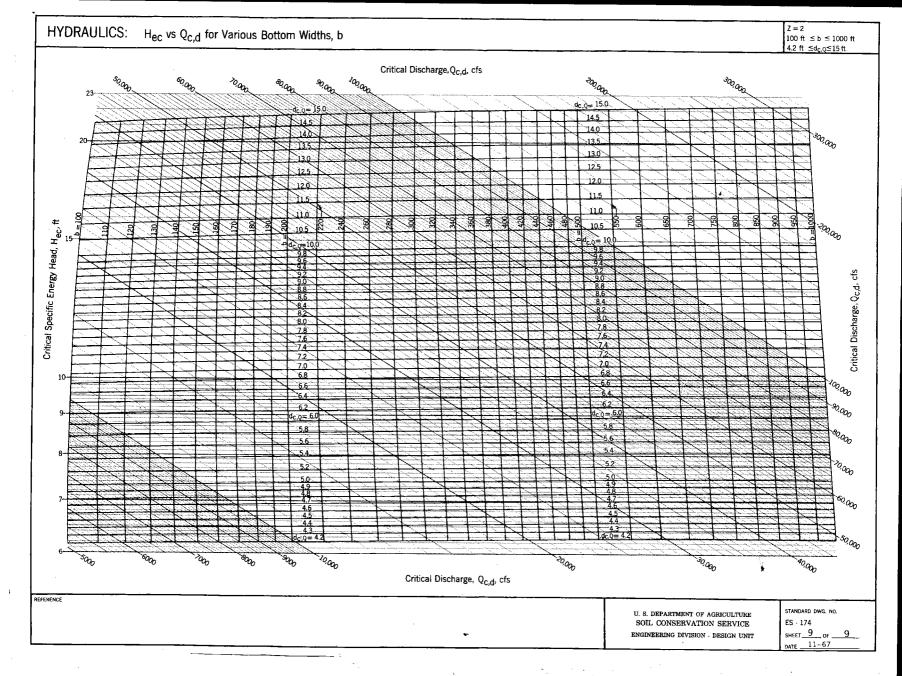


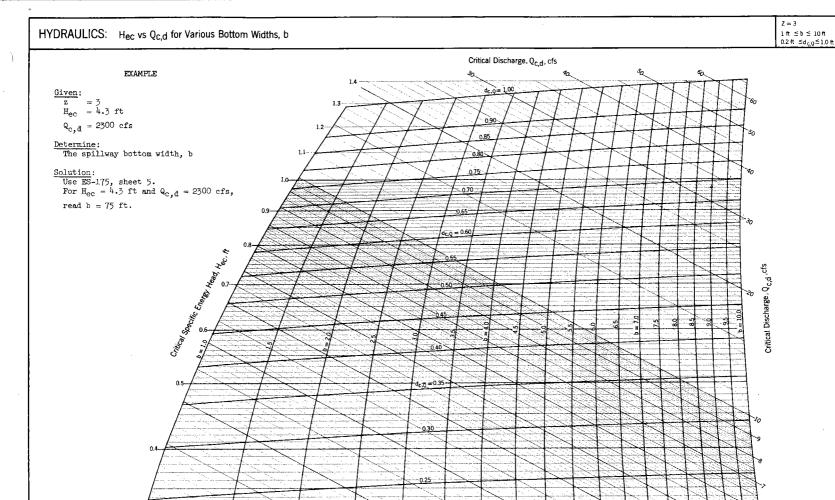








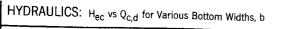




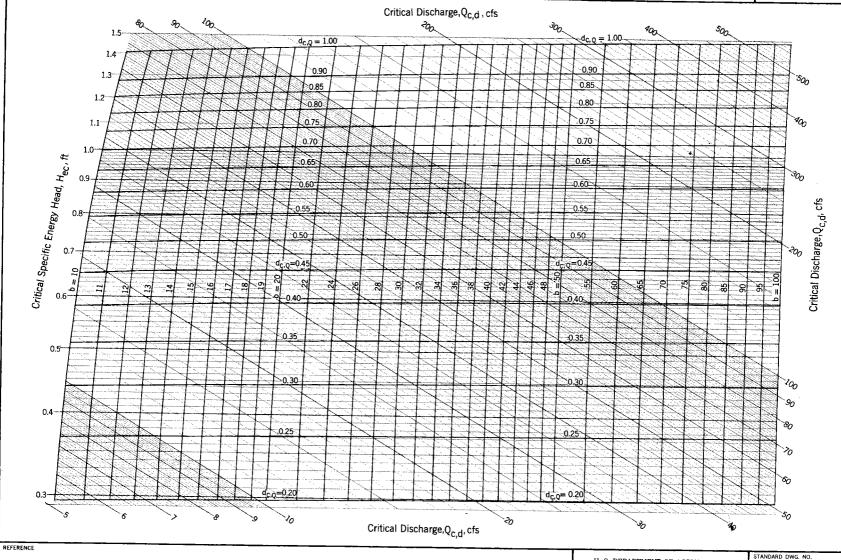
.dc.o = 0.20.

Critical Discharge, Q<sub>c,d</sub>, cfs

REFERENCE

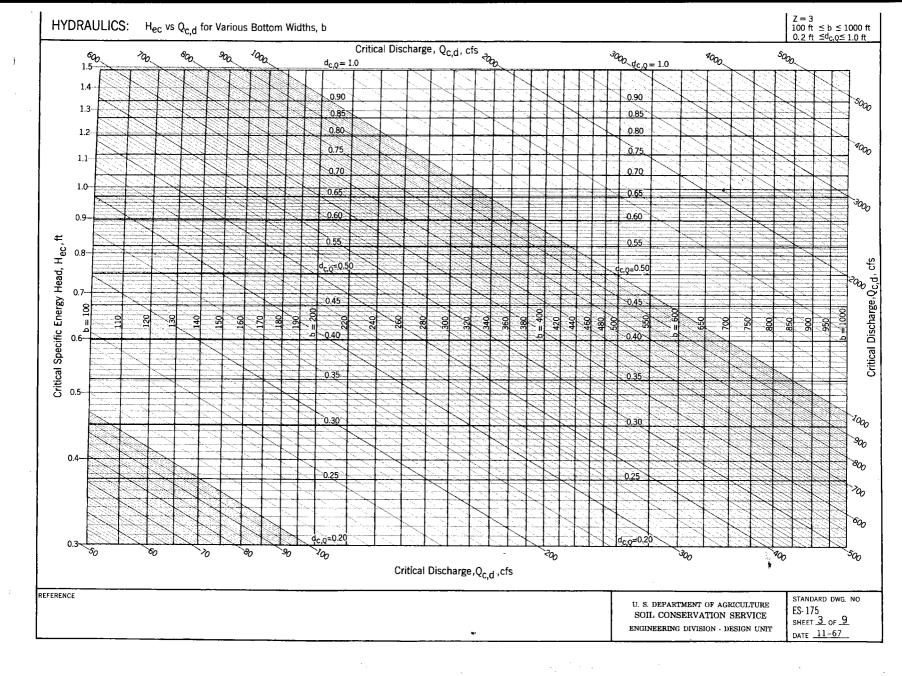
U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT 

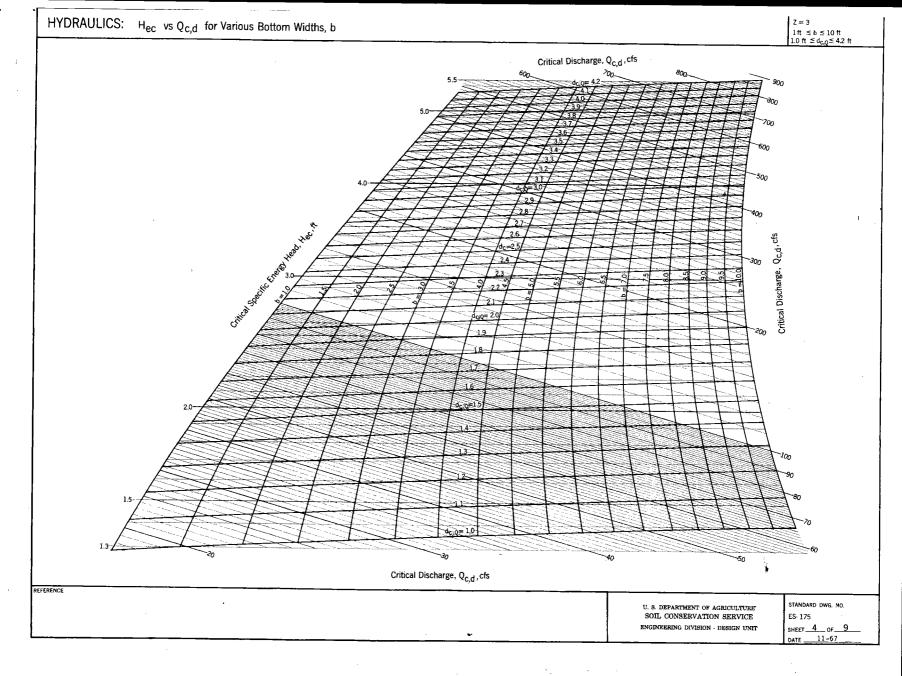
 $10 \text{ ft } \le b \le 100 \text{ ft}$  $0.2 \text{ ft } \le d_{c,Q} \le 1.0 \text{ ft}$ 

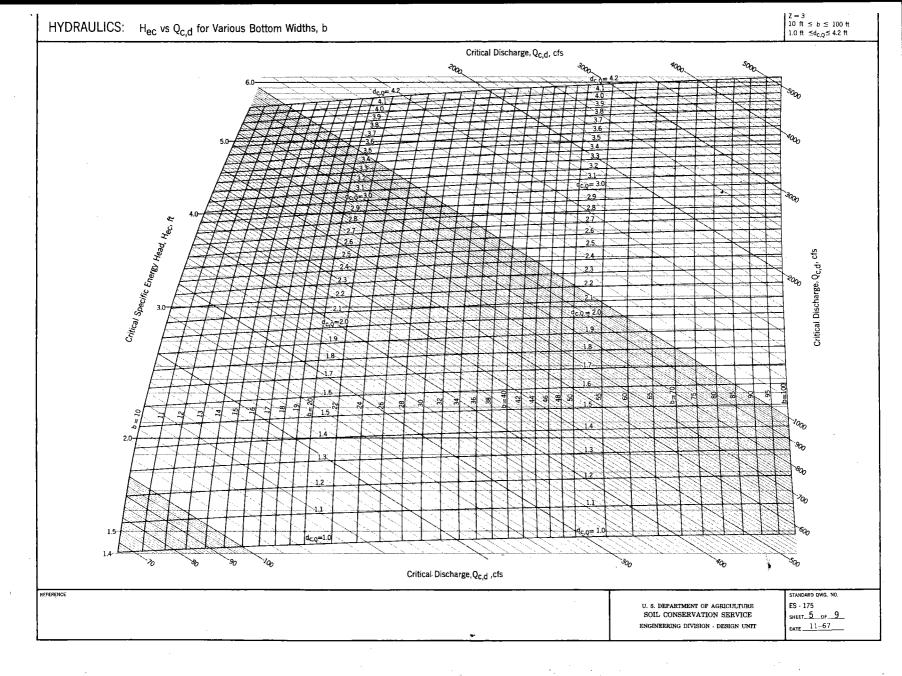


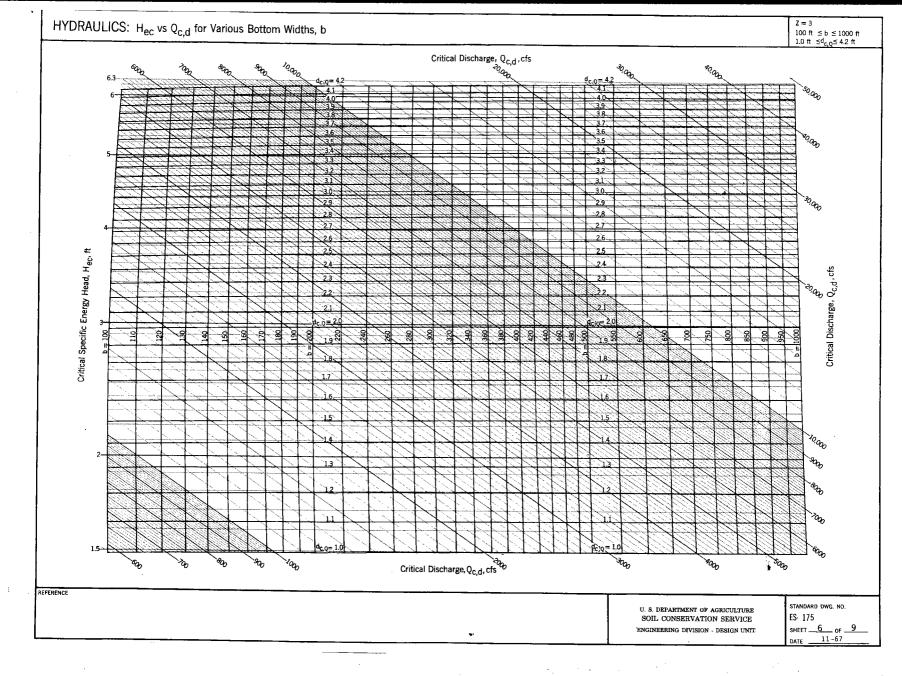
U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT

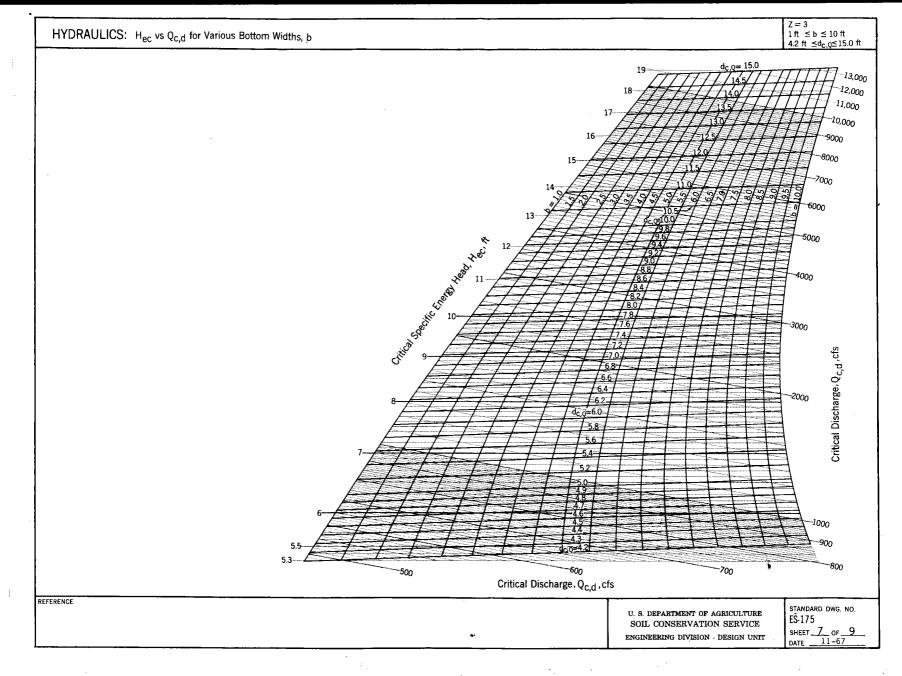
ES - 175 SHEET 2 OF 9 DATE 11-67

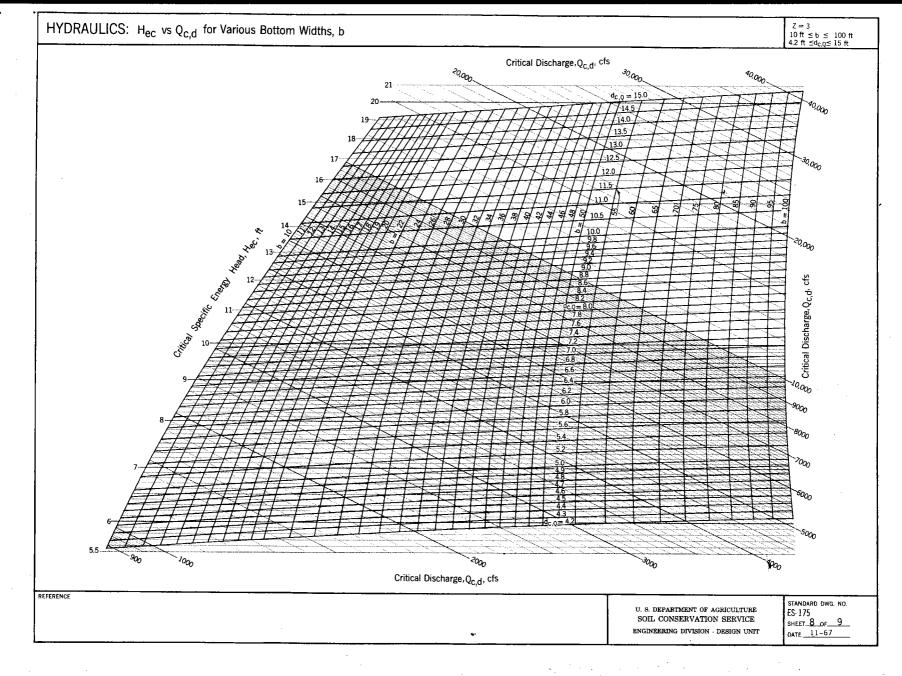


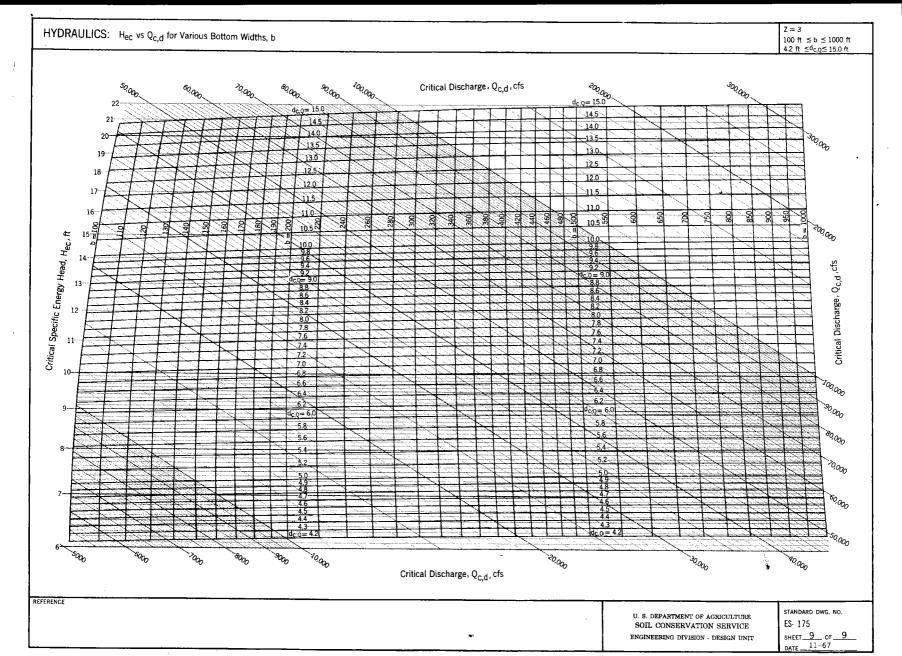


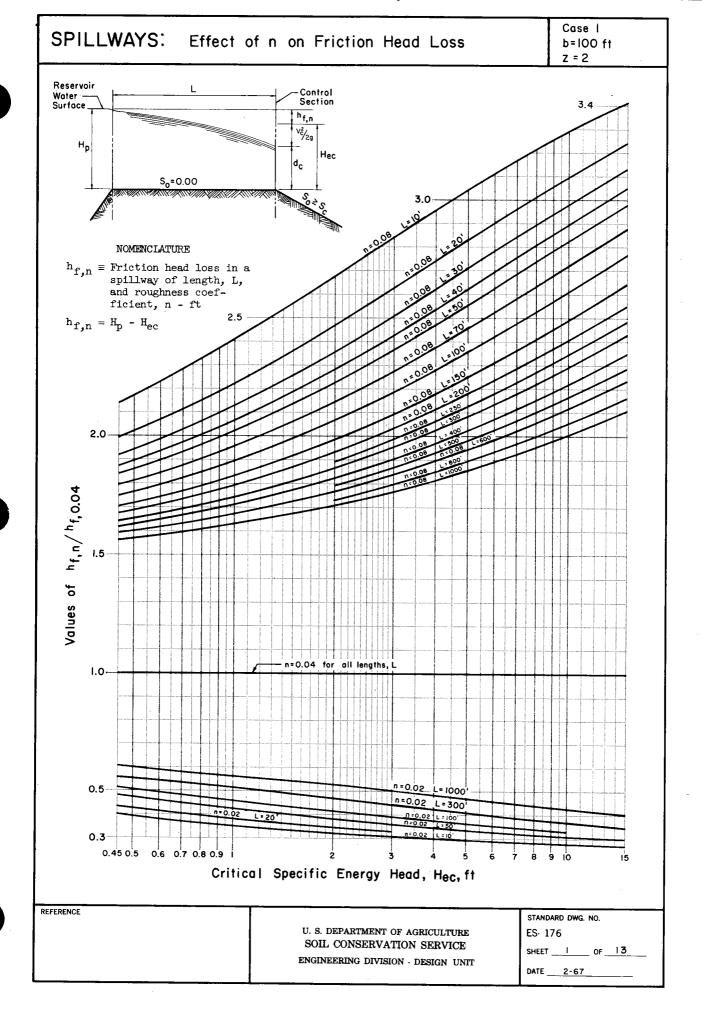












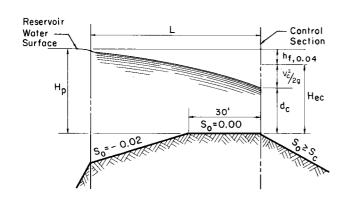
SPILLWAYS:

Effect of n on Friction Head Loss for n = 0.04

Case 2 b = 100 ft z = 2

1.0

1.2



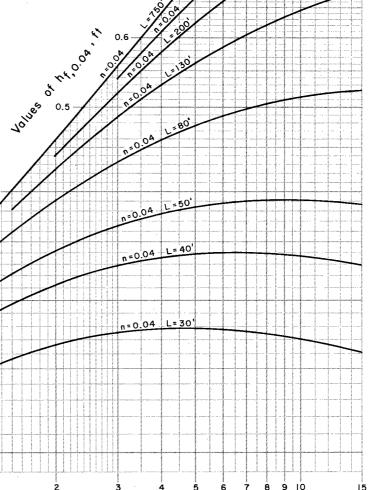
#### NOMENCLATURE

0.3

0.45 0.5 0.6 0.7 0.8 0.9

 $\begin{array}{c} h_{\mbox{f,0.04}} \equiv \mbox{Friction head loss in a spillway} \\ \mbox{of length, L, and roughness coefficient of 0.04 - ft} \end{array}$ 

 $h_{f,0.04} = H_p - H_{ec}$ 



0.8

Critical Specific Energy Head, H<sub>ec</sub>, ft

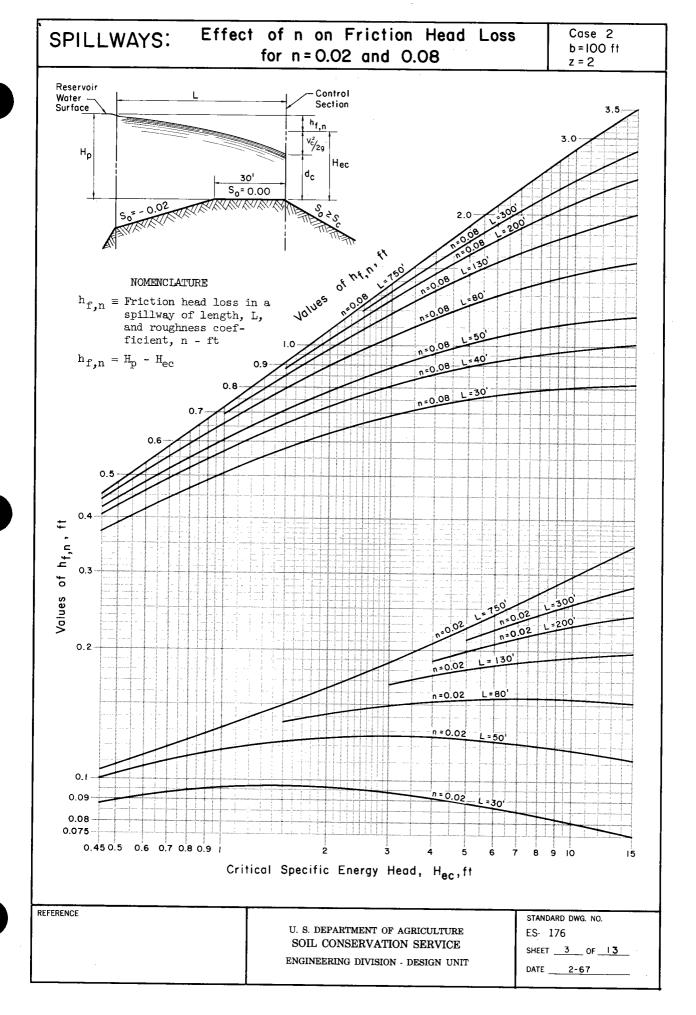
REFERENCE

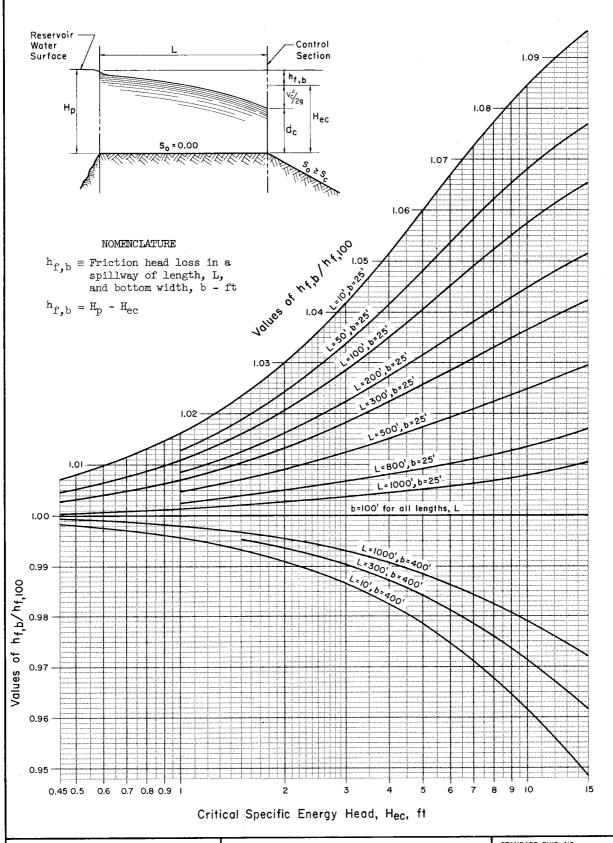
U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT STANDARD DWG. NO.

ES- 176

SHEET 2 OF 13

DATE 2-67

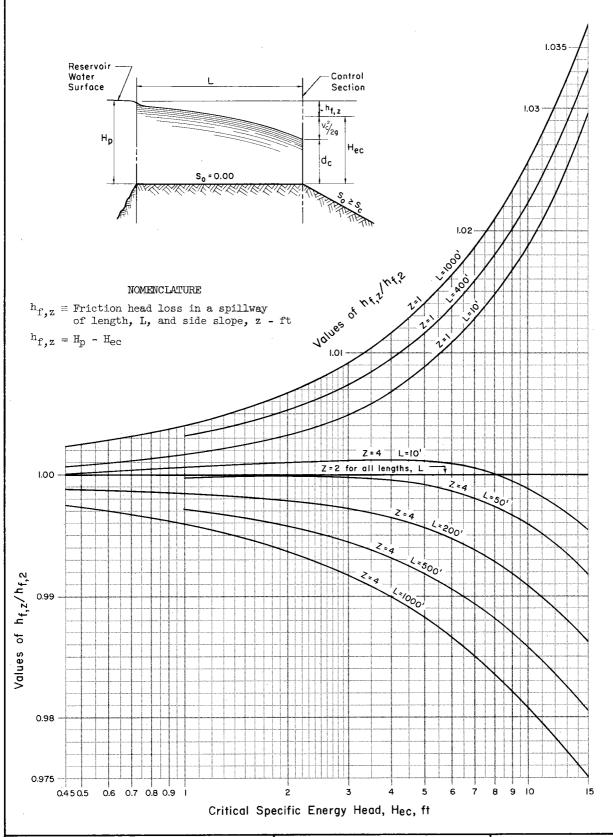




REFERENCE

U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT STANDARD DWG. NO.
ES- 176
SHEET 4 OF 13
DATE 2-67

Case 2 SPILLWAYS: Effect of b on Friction Head Loss n = 0.04z = 2Maximum Deviation of  $h_{f,b}$  is 0.028 for L=750 curve. L=750' 1.1 Reservoir Control Water Section 1.0 Surface h<sub>f,b</sub> Vc/2g  $H_{\mathbf{p}}$ Hec L=200' dc 30  $S_0 = 0.00$ L=130' NOMENCLATURE  $h_{f,b} \equiv Friction head loss in a$ b=25 spillway of length, L, and bottom width, b - ft p=100' L=80' b=400  $h_{f,b} = H_p - H_{ec}$ b=25' p=100, L=50' b=400' b=25 b=100 L=40' b=400' L=301 0.2 0.19 0.45 0.5 0.6 0.7 0.8 0.9 1 8 9 10 15 Critical Specific Energy Head, Hec, ft REFERENCE STANDARD DWG. NO. U. S. DEPARTMENT OF AGRICULTURE ES- 176 SOIL CONSERVATION SERVICE SHEET \_ 5 OF \_ 13 ENGINEERING DIVISION - DESIGN UNIT DATE 2-67



REFERENCE

U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT

STANDARD DWG. NO. ES- 176 SHEET \_\_6 OF \_\_13 DATE 2-67

Case 2 SPILLWAYS: Effect of z on Friction Head Loss b = 100 ft n = 0.04Reservoir Water Surface Control Section h<sub>f,z</sub> Vc/2g  $H_p$ 30' Hec dc s<sub>o</sub> = 0.00 NOMENCLATURE  $\mathbf{h}_{\text{f,z}} \equiv \text{Friction head loss in a spillway}$  of length, L, and side slope, z - ft  $h_{f,z} = H_p - H_{ec}$ L=80', Z= L=50', Z=4 L=40', Z=1 L=40', Z=4

Critical Specific Energy Head, Hec, ft

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN UNIT

0.45 0.5 0.6 0.7 0.8 0.9

STANDARD DWG. NO.
ES- 176
SHEET \_ 7 \_\_ OF \_ 13

DATE \_ 2-67

L=30', Z=1 L=30', Z=4

9 10

## SPILLWAYS: Examples-Effect of n, b, and z on Friction **Head Loss**

#### EXAMPLE 1

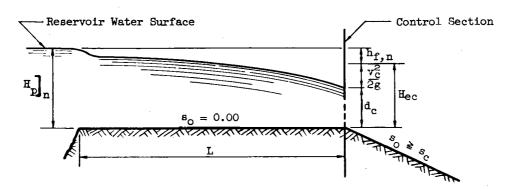
Given:

Emergency spillway bottom profile as shown in figure  $H_{ec} = 4.50 \text{ ft}$ 

$$z = 2$$

$$L = 200 \text{ ft}$$

$$H_p$$
 = 5.51 ft (obtained from ES-171, sheet 1)



### Determine:

$$H_{p}$$
 n=0.08

Solution:  
1. 
$$h_{f,0.04} = H_{p}$$
 -  $H_{ec} = 5.51 - 4.50 = 1.01 ft$ 

2. Use ES-176, sheet 1. For 
$$H_{ec}$$
 = 4.50 ft, n = 0.08, and L = 200 ft, read  $\frac{h_{f,0.08}}{h_{f,0.04}}$  = 2.15. Then  $h_{f,0.08}$  = 2.15 ( $h_{f,0.04}$ ) = 2.15(1.01) = 2.17 ft  $H_{p}$  =  $H_{ec}$  +  $h_{f,0.08}$  = 4.50 + 2.17 = 6.67 ft

REF	ERE	NCE
-----	-----	-----

# SPILLWAYS: Examples-Effect of n, b, and z on Friction Head Loss

#### EXAMPLE 2

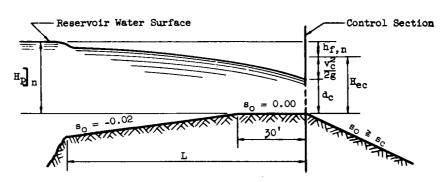
#### Given

Emergency spillway bottom profile as shown in figure

$$H_{ec} = 4.50$$
 ft

$$z = 2$$

$$L = 200 \text{ ft}$$



#### Determine:

$$H_{p}$$
 where n = 0.02, 0.04, 0.08, and 0.05.

#### Solution:

## 1. Determine Hp n=0.02

Use ES-176, sheet 3.

For 
$$H_{ec} = 4.50$$
 ft,  $n = 0.02$ , and  $L = 200$  ft, read  $h_{f,0.02} = 0.20$  ft.

Then 
$$H_p$$
 =  $H_{ec} + h_{f,0.02} = 4.50 + 0.20 = 4.70 ft$ 

## 2. Determine $H_p$ $_{n=0.04}$

Use ES-176, sheet 2.

For 
$$H_{ec} = 4.50$$
 ft,  $n = 0.04$ , and  $L = 200$  ft, read  $h_{f,0.04} = 0.60$  ft.

For 
$$n = 0.04$$
,  $H_p$   $_{n=0.04}$  =  $H_{ec}$  +  $h_{f,0.04}$  = 4.50 + 0.60 = 5.10 ft.

3. Determine Hp n=0.08

For 
$$H_{ec} = 4.50$$
 ft,  $n = 0.08$ , and  $L = 200$  ft, read  $h_{f,0.08} = 1.54$  ft.

Then 
$$H_{p}$$
 =  $H_{ec} + h_{f,0.08} = 4.50 + 1.54 = 6.04 ft.$ 

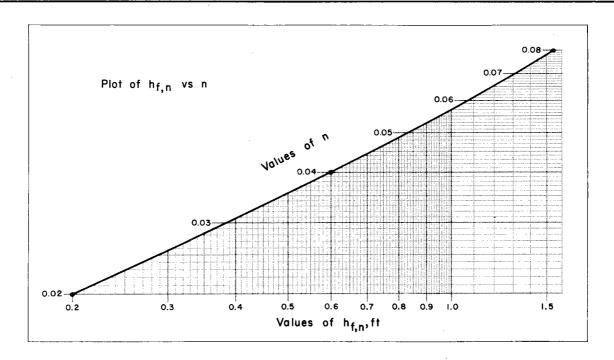
## 4. Determine Hp n=0.05

Prepare plot of  $h_{f,n}$  vs n.

From plot read  $h_{f,0.05} = 0.83$  ft.

Then 
$$H_p$$
<sub>n=0.05</sub> =  $H_{ec} + h_{f,0.05} = 4.50 + 0.83 = 5.33 ft.$ 

### SPILLWAYS: Examples-Effect of n, b, and z on Friction **Head Loss**



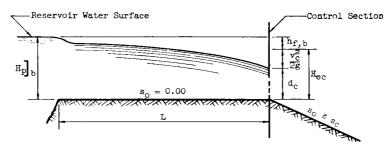
#### EXAMPLE 3

Emergency spillway bottom profile as shown in figure  $H_{ec} = 4.50 \text{ ft}$ z = 2

$$L = 200 \text{ ft}$$

$$n = 0.04$$

$$H_{\rm p}$$
 = 5.51 ft (obtained from ES-171, sheet 1)



#### Determine:

Solution:  
1. 
$$h_{f,100} = H_p$$
  $b=100$  -  $H_{ec} = 5.51 - 4.50 = 1.01 ft$ 

2. Use ES-176, sheet 4. For 
$$H_{ec}$$
 = 4.50 ft, b = 400 ft, and L = 200 ft, read  $\frac{h_{f,400}}{h_{f,100}}$  = 0.985. Then  $h_{f,400}$  = 0.985( $h_{f,100}$ ) = 0.985(1.01) = 0.99 ft.

$$H_p$$
<sub>b=400</sub> =  $H_{ec}$  +  $h_{f,400}$  = 4.50 + 0.99 = 5.49 ft

#### REFERENCE

U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE

**ENGINEERING DIVISION - DESIGN UNIT** 

STANDARD DWG. NO. ES-176 SHEET 10 OF 13

DATE \_ 6 - 67

# SPILLWAYS: Examples-Effect of n, b, and z on Friction Head Loss

#### EXAMPLE 4

#### Given:

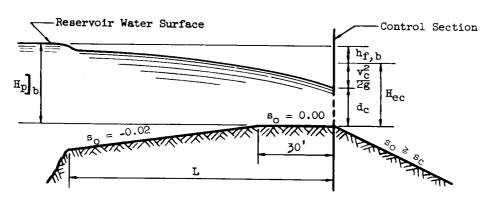
Emergency spillway bottom profile as shown in figure

$$H_{ec} = 6.00 \text{ ft}$$

$$z = 2$$

$$L = 300 \text{ ft}$$

$$n = 0.04$$



#### Determine:

$$H_p$$
 where b = 25, 100, and 400 ft

### Solution:

1. Use ES-176, sheet 5.

For 
$$L = 300$$
 ft and

$$b = 25$$
 ft, read  $h_{f,25} = 0.73$  ft;

$$b = 100 \text{ ft, read } h_{f,100} = 0.72 \text{ ft;}$$

$$b = 400 \text{ ft, read } h_{f,400} = 0.70 \text{ ft.}$$

2. Then where

$$b = 25 \text{ ft}, H_p]_{b=25} = H_{ec} + h_{f,25} = 6.00 + 0.73 = 6.73 \text{ ft};$$

$$b = 100 \text{ ft}$$
,  $H_p$ <sub>b=100</sub> =  $H_{ec} + h_{f,100} = 6.00 + 0.72 = 6.72 \text{ ft}$ ;

$$b = 400 \text{ ft}$$
,  $H_p$   $b = 400 = H_{ec} + h_{f,400} = 6.00 + 0.70 = 6.70 \text{ ft}$ .

REFERENCE

U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE

ENGINEERING DIVISION - DESIGN UNIT

STANDARD DWG. NO.
ES-176
SHEET 11 OF 13

DATE 6-67

## SPILLWAYS: Examples-Effect of n, b, and z on Friction **Head Loss**

#### EXAMPLE 5

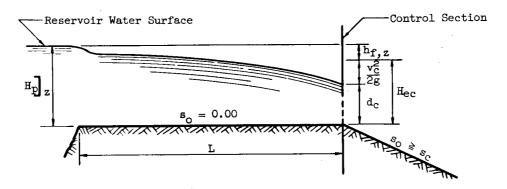
#### Given:

Emergency spillway bottom profile as shown in figure

$$H_{ec} = 4.50 \text{ ft}$$

$$n = 0.04$$

$$H_p$$
<sub>z=2</sub> = 5.51 ft (obtained from ES-171, sheet 1)



#### Determine:

$$H_{p}$$

Solution:  
1. 
$$h_{f,z} = H_p$$
 = 5.51 - 4.50 = 1.01 ft

For 
$$H_{ec}$$
 = 4.50 ft,  $z$  = 4, and  $L$  = 200 ft, read  $\frac{h_{f,4}}{h_{f,2}}$  = 0.996.

Then 
$$h_{f,4} = 0.996(h_{f,2}) = 0.996(1.01) = 1.01 ft.$$

$$H_{p}$$
<sub>z=4</sub> =  $H_{ec}$  +  $h_{f,4}$  = 4.50 + 1.01 = 5.51 ft

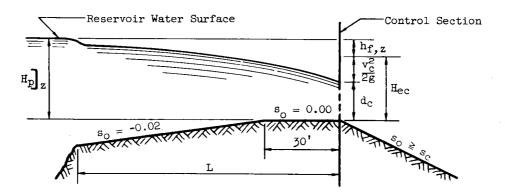
## SPILLWAYS: Examples-Effect of n, b, and z on Friction Head Loss

#### EXAMPLE 6

#### Given:

Emergency spillway bottom profile as shown in figure

$$H_{ec} = 7.50 \text{ ft}$$
  
b = 100 ft  
L = 300 ft



#### Determine:

$$H_p$$
 where  $z = 1, 2, and 4$ 

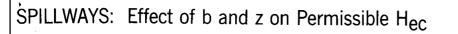
#### Solution:

1. Use ES-176, sheet 7. For L = 300 ft and z = 1, read  $h_{f,1} = 0.80$  ft; z = 2, read  $h_{f,2} = 0.78$  ft; z = 4, read  $h_{f,4} = 0.76$  ft.

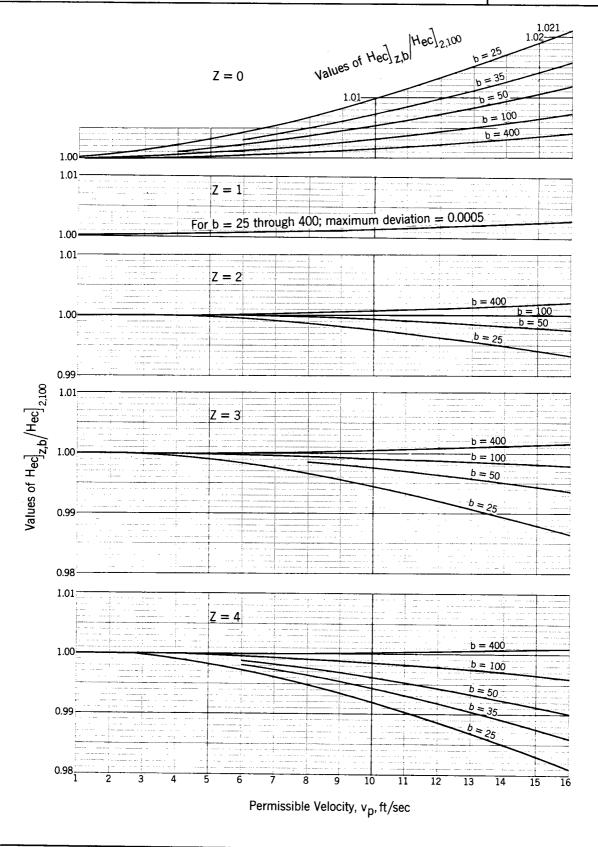
2. Then where 
$$z = 1$$
,  $H_p$  =  $H_{ec} + h_{f,1} = 7.50 + 0.80 = 8.30$  ft;  $z = 2$ ,  $H_p$  =  $H_{ec} + h_{f,2} = 7.50 + 0.78 = 8.28$  ft;  $z = 4$ ,  $H_p$  =  $H_{ec} + h_{f,4} = 7.50 + 0.76 = 8.26$  ft.

**ENGINEERING DIVISION - DESIGN UNIT** 

. 1



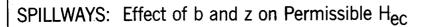
 $\frac{n^2}{s_0} = 0.002$ Z = 1, 2, 3, and 4



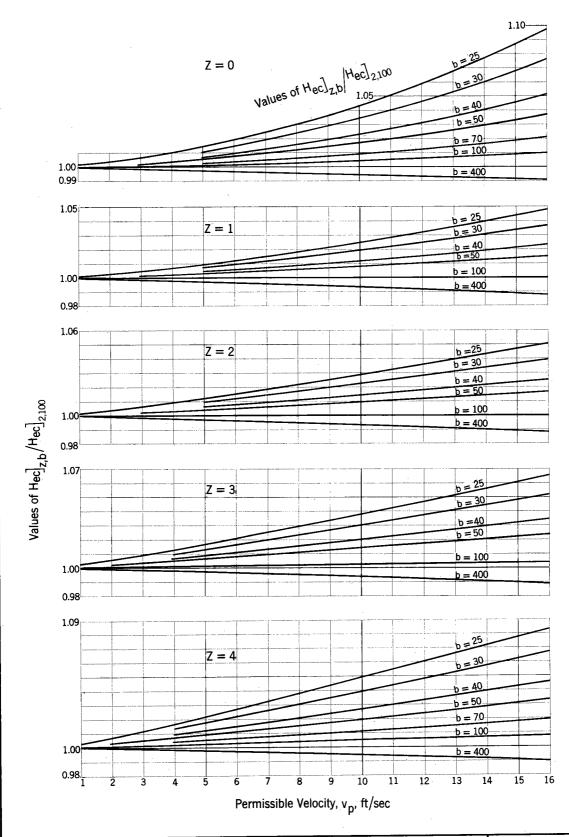
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN UNIT

STANDARD DWG. NO.

ES-177
SHEET 1 OF 8
DATE 1-68

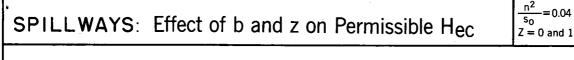


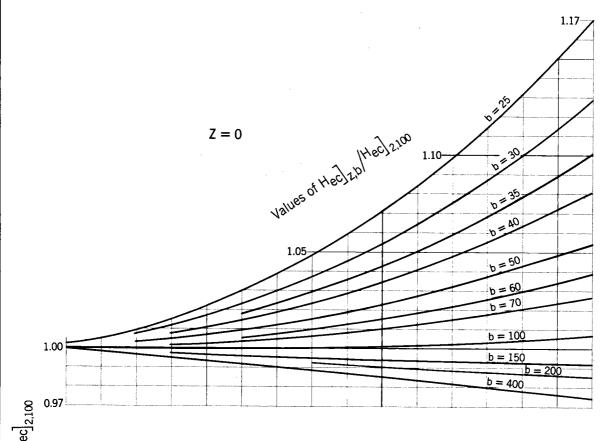
 $\frac{n^2}{s_0} = 0.02$ Z = 0, 1, 2, 3, and 4

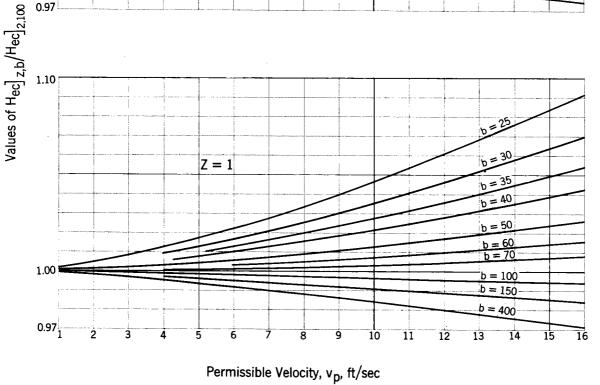


REFERENCE

U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION . DESIGN UNIT STANDARD DWG. NO.
ES-177
SHEET 2 OF 8
DATE 1-68





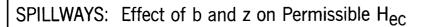


REFERENCE

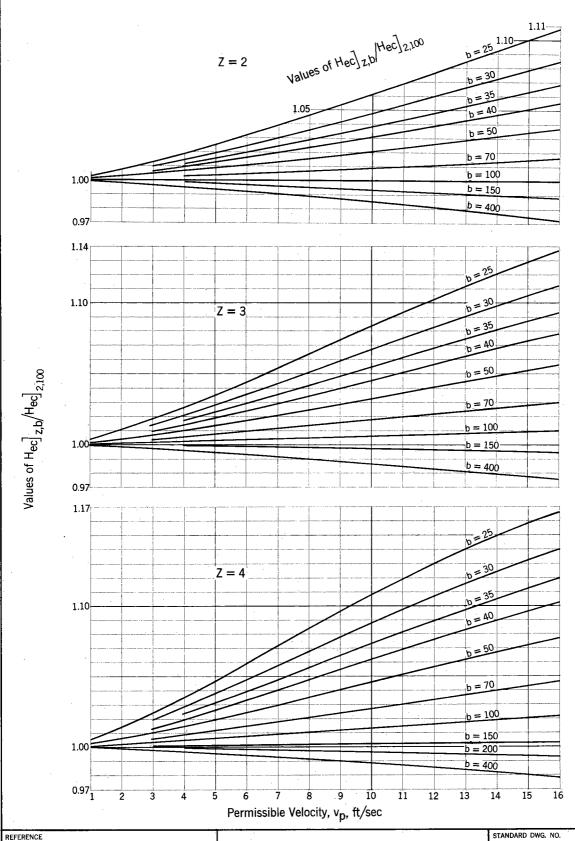
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN UNIT

STANDARD DWG. NO.

ES-177
SHEET 3 OF 8
DATE 1-68

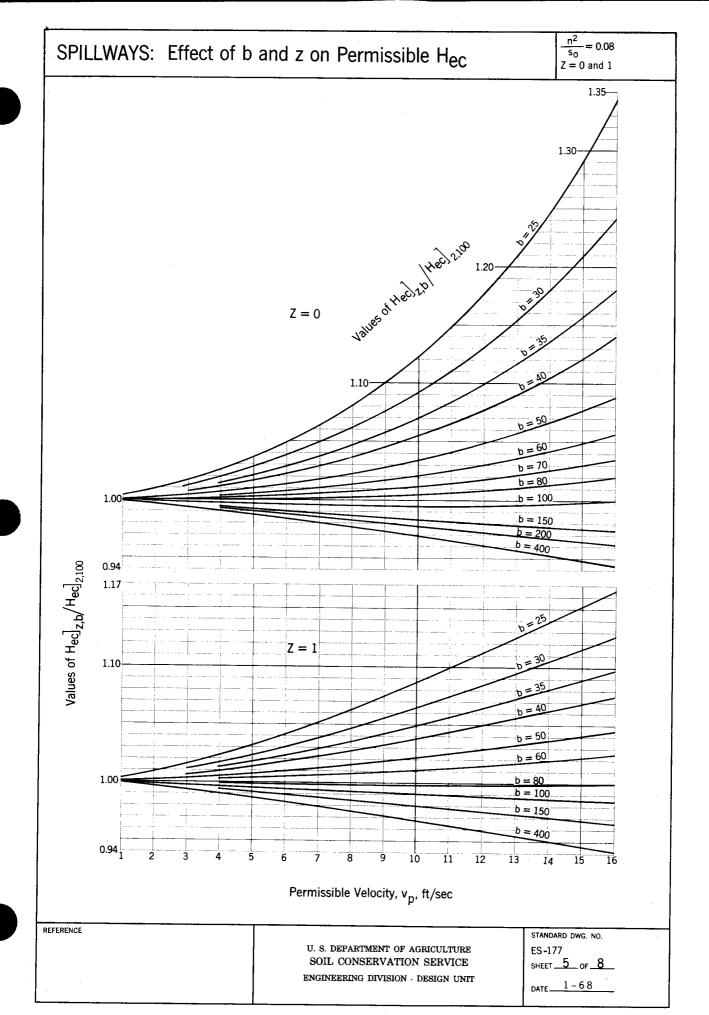


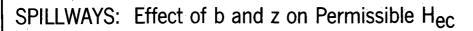




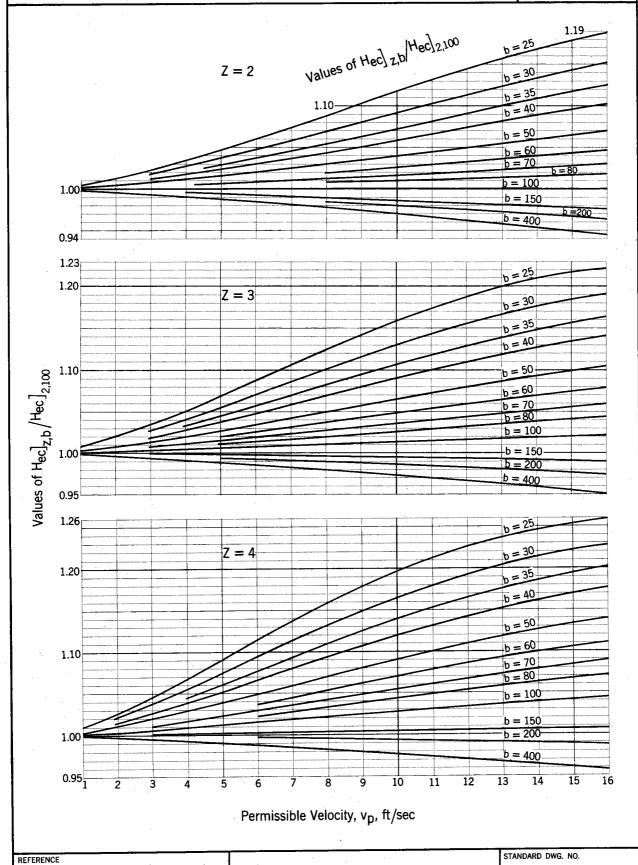
U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT

ES-177 SHEET 4 OF 8 DATE 1-68









U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT ES-177 SHEET 6 OF 8 DATE 1 - 68

## SPILLWAYS: Examples-Effect of b and z on Permissible Hec

#### NOMENCLATURE

Hecle\_{2,100}  $\equiv$  the permissible critical specific energy head for a spillway with z = 2 and b = 100 ft - ft

 $\equiv$  the permissible critical specific energy head for a spillway with side slopes, z, and bottom width, b - ft

 $s_0 \equiv the exit channel bottom slope - ft/ft$ 

#### EXAMPLE 1

#### Given:

Emergency spillway bottom profile as shown in figure

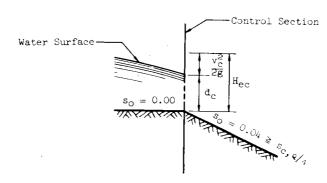
$$z = 3$$

$$b = 50 \text{ ft}$$

$$n = 0.04$$

$$v_p = 8 ft/sec$$

$$H_{ec}$$
<sub>2.100</sub> = 2.06 ft (obtained from ES-170, sheet 1)



#### Determine:

Permissible Hec 3.50

#### Solution:

1. Compute 
$$\frac{n^2}{s_0}$$

$$\frac{n^2}{s_0} = \frac{(0.04)^2}{0.04} = 0.04$$

2. Use ES-177, sheet 4. For z = 3, b = 50 ft, and 
$$v_p$$
 = 8 ft/sec, read

$$H_{ec}$$
<sub>z,b</sub> $/H_{ec}$ <sub>2,100</sub> = 1.025.

Then 
$$H_{ec}$$
<sub>3,50</sub> = 1.025  $H_{ec}$ <sub>2,100</sub> = 1.025(2.06) = 2.11 ft

REFERENCE

U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE

ENGINEERING DIVISION - DESIGN UNIT

STANDARD DWG. NO. ES-177

SHEET 7 OF 8

DATE 2-68

## SPILLWAYS: Examples-Effect of b and z on Permissible Hec

#### EXAMPLE 2

#### Given:

Emergency spillway bottom profile as shown in figure for Example 1 except that the exit channel bottom slope,  $s_0$ , is equal to 0.052.

$$z = 4$$

$$b = 70 \text{ ft}$$

$$n = 0.04$$

$$v_p = 6.0 \text{ ft/sec}$$

$$H_{eQ}_{2,100} = 1.12$$
 ft (obtained from ES-170, sheet 1)

#### Determine:

Permissible Hec 4.70

#### Solution:

1. Compute 
$$\frac{n^2}{s_0}$$

$$\frac{n^2}{s_0} = \frac{(0.04)^2}{0.052} = 0.0308$$

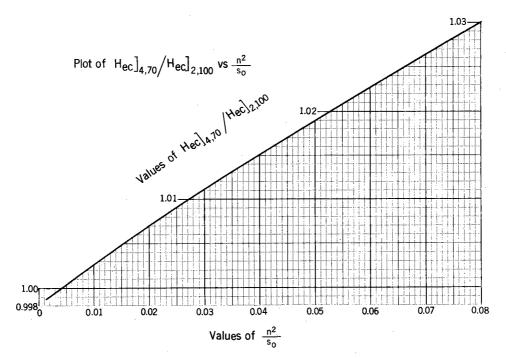
2. Use ES-177. For z = 4, b = 70 ft, and  $v_p$  = 6 ft/sec, read values of

$$\text{Hec}_{z,b}/\text{Hec}_{z,100}$$
 for  $\frac{n^2}{s_0}$  values of 0.002, 0.02, 0.04, and 0.08.

3. Plot 
$$H_{ec}$$
<sub>4,70</sub>/ $H_{ec}$ <sub>2,100</sub> vs  $\frac{n^2}{s_0}$ 

4. For 
$$\frac{n^2}{s_0} = 0.0308$$
, read from the plot  $H_{ec}$ <sub>4,70</sub>/ $H_{ec}$ <sub>2,100</sub> = 1.011.

Then  $H_{ec}$ <sub>4.70</sub> = 1.011  $H_{ec}$ <sub>2.100</sub> = 1.011(1.12) = 1.13 ft



REFERENCE

U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE

**ENGINEERING DIVISION - DESIGN UNIT** 

STANDARD DWG. NO. ES-177

SHEET 8 OF 8

DATE 2 - 68

## SPILLWAYS: Effect of b on Critical Slope

15.0

10.0

9.0

8.0

7.0

6.0

4.0

Z = 0n = 0.04



 $s_{c,\,Q/4}$   $\equiv$  the critical slope corresponding to a discharge of Q/4 - ft/ft

#### EXAMPLE

#### Given:

An emergency spillway

= 50 ft

= 0.04

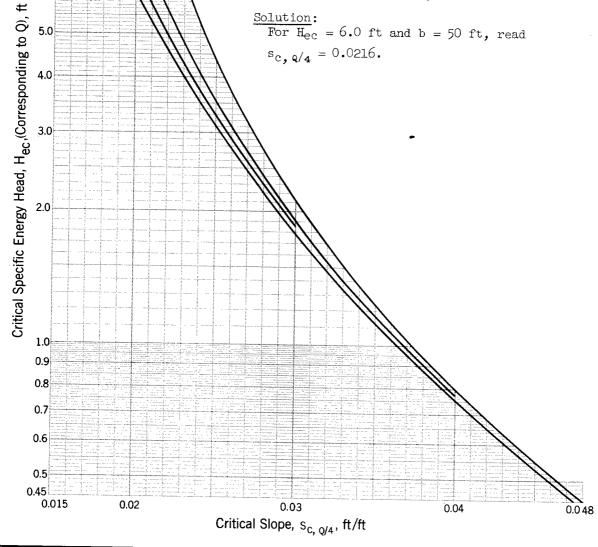
 $H_{ec} = 6.0 \text{ ft}$ 

#### Determine:

The critical slope, sc, Q/4

Solution: For  $H_{ec} = 6.0$  ft and b = 50 ft, read

 $s_{c, Q/4} = 0.0216.$ 



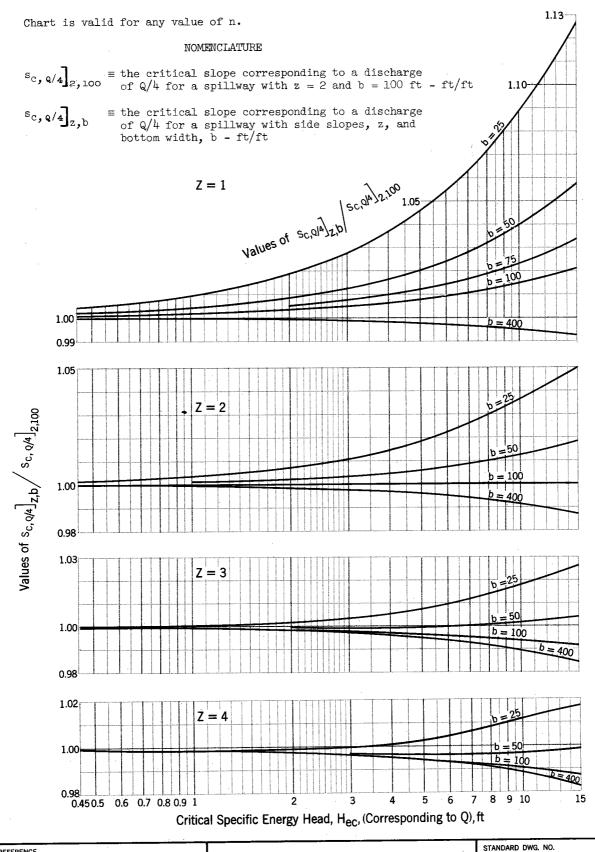
REFERENCE

U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT

STANDARD DWG. NO. ES - 178 SHEET 1\_OF 3 DATE \_\_\_\_1 - 68

## SPILLWAYS: Effect of b and z on Critical Slope

Z = 1, 2, 3, and 4



REFERENCE

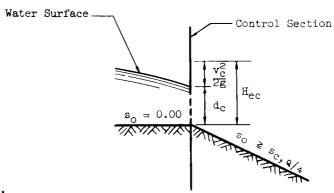
U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT STANDARD DWG. NO.
ES - 178
SHEET 2 OF 3
DATE 1 - 68

## SPILLWAYS: Example-Effect of b and z on Critical Slope

#### EXAMPLE

#### Given:

$$H_{ec} = 4.5 \text{ ft}$$
 $z = 1$ 
 $b = 75 \text{ ft}$ 
 $n = 0.04$ 
 $s_{c, Q/4}$ 
 $c_{c, Q/4}$ 
 $s_{c, Q/4}$ 
 $c_{c, Q/4}$ 
 $s_{c, Q/4}$ 
 $c_{c, Q/4}$ 
 $c_{c, Q/4}$ 
 $c_{c, Q/4}$ 



#### Determine:

#### Solution:

Use ES-178, sheet 2.  
For z = 1, b = 75 ft, and 
$$H_{ec} = 4.5$$
 ft, read  $s_{c,q/4} \Big|_{z,b} / s_{c,q/4} \Big|_{z,100} = 1.011$   
Then  $s_{c,q/4} \Big|_{1,75} = 1.011 \Big( s_{c,q/4} \Big|_{2,100} \Big) = (1.011)(0.0221) = 0.0223$ 

REFERENCE

U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE

ENGINEERING DIVISION - DESIGN UNIT

STANDARD DWG. NO. ES-178 SHEET 3 OF 3

DATE 2-68

#### EXAMPLE 1

#### Given:

Emergency spillway bottom profile as shown in figure

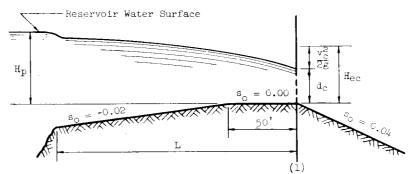
$$z = 2$$

b = 100 ft

n = 0.04

L = 300 ft

 $v_p = 6 \text{ ft/sec}$ 



#### Determine:

- I. Permissible Hec
- II. The discharge, Q, corresponding to the permissible  ${\rm H}_{\rm ec}$
- III. Critical slope for Q/4, sc, q/4
- IV. The energy head,  $H_p$ , above the crest at the distance, L, upstream from section (1)

#### Solution:

- I. Determine permissible  $H_{ec}$  Use ES-170, sheet 1. For  $s_0$  = 0.04 and  $v_p$  = 6 ft/sec, read permissible  $H_{ec}$  = 1.28 ft.
- II. Determine Q Use ES-174, sheet 2. For  $H_{ec} = 1.28$  ft and b = 100 ft, read Q = 457 cfs.
- III. Determine  $s_{c, Q/4}$

Use ES-170, sheet 1 or ES-172, sheet 1.

For  $H_{ec} = 1.28$  ft, read  $s_{c, \sqrt{4}} = 0.0334$ .

Since the exit channel bottom slope,  $s_o$ , is greater than  $s_c, q/4$ , a control section exists at section (1) for discharges in the interval Q/4 to Q.

REFERENCE

U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE

ENGINEERING DIVISION - DESIGN UNIT

STANDARD DWG. NO.

ES-179

SHEET 1 OF 4

DATE 2-68

# SPILLWAYS: Examples Showing the Interrelation of Drawings ES-170 through ES-178

#### EXAMPLE 2

#### Given:

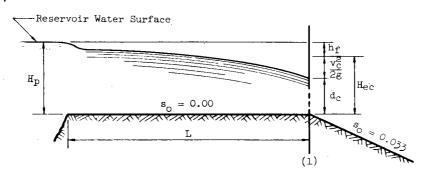
Emergency spillway bottom profile as shown in figure

$$z = 3$$

$$n = 0.035$$

$$L = 200 \text{ ft}$$

$$v_p = 7 \text{ ft/sec}$$



#### Determine:

- I. For b = 100 ft, z = 2, and n = 0.035
  - A. Permissible Hec
  - B. The energy head, Hp, corresponding to the permissible Hec
- II. The required spillway bottom width, b, assuming that the routing of the emergency spillway hydrograph yields a maximum discharge, Q, of 450 cfs corresponding to the permissible  $H_{\rm D}$ .
- III. For the b determined in II, z = 3, and n = 0.035
  - A. Permissible Hec
  - B. s<sub>c</sub>, √4
  - C.  $H_p$  corresponding to the permissible  $H_{ec}$

#### Solution:

- I. For b = 100 ft, z = 2, and n = 0.035
  - A. Determine permissible  $H_{ec}$ Use ES-170, sheet 1.
    Since the value of n is not 0.04, the abscissa of sheet 1 will be redesignated as  $\left[\frac{0.04}{n}\right]^2$  s<sub>0</sub>.

For 
$$\left[\frac{0.04}{n}\right]^2 s_0 = \left[\frac{0.04}{0.035}\right]^2 \left[0.033\right] = 0.0431$$
 and  $v_p = 7$  ft/sec, read permissible  $H_{ec} = 1.58$  ft.

- B. Determine H<sub>D</sub>
  - 1. Use ES-171, sheet 1. For  $H_{ec}=1.58$  ft, L=200 ft, and n=0.04, read  $H_p=2.35$  ft. Then the head loss,  $h_{f,0.04}$ , assuming n=0.04 is  $h_{f,0.04}=H_p-H_{ec}=2.35-1.58=0.77$  ft

REFERENCE

U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE

ENGINEERING DIVISION - DESIGN UNIT

STANDARD DWG. NO.

ES-179

SHEET 2 OF 4

DATE 2 - 68

# SPILLWAYS: Examples Showing the Interrelation of Drawings ES-170 through ES-178

- 2. Use ES-176, sheet 1 and a graphical procedure similar to that used in Example 2 of ES-176. For  $H_{ec}=1.58$  ft, L=200 ft, and n=0.035, obtain  $h_{f,0.035}/h_{f,0.04}=0.87$ .  $h_{f,0.035}=0.87(h_{f,0.04})=0.87(0.77)=0.67$  ft The value of  $H_p$  adjusted for the n value is given by  $H_p=H_{ec}+h_{f,0.035}=1.58+0.67=2.25$  ft
- II. Determine b with z=3Use ES-175, sheet 5. For  $H_{ec}=1.58$  ft and Q=450 cfs, read b=70 ft.
- III. For b = 70 ft, z = 3, and n = 0.035 A. Determine permissible  $H_{ec}$ Use ES-177 and the procedure used in Example 2 of ES-177.  $\frac{n^2}{s_0} = \frac{(0.035)^2}{0.033} = 0.0371$ For z = 3, b = 70 ft, and  $v_p = 7$  ft/sec, obtain  $H_{ec}$ <sub>3,70</sub>/ $H_{ec}$ <sub>2,100</sub> = 1.01.  $H_{ec}$ <sub>3,70</sub> = 1.01  $H_{ec}$ <sub>2,100</sub> = 1.01(1.58) = 1.60 ft
  - B. Determine sc, 9/4
    - 1. Use ES-172, sheet 1. Since the value of n is not 0.04, the abscissa of ES-172, sheet 1 will be redesignated  $\left[\frac{0.04}{n}\right]^2 s_c$ ,  $\frac{1}{2}s_c$ ,  $\frac{1}{$
    - 2. Use ES-178, sheet 2. For z = 3, b = 70 ft, and  $H_{ec} = 1.60$  ft, read  $s_c$ , q/4,  $s_c$ , q/4,  $s_c$ , q/4,  $s_c$ ,  $s_c$ , s

This is the  $s_{c, Q/4}$  for z = 3, b = 70 ft,  $H_{ec} = 1.60$  ft, and n = 0.035. The exit channel bottom slope,  $s_{o}$ , is greater than  $s_{c, Q/4}$ ; therefore, a control section exists at section (1) for discharges in the interval Q/4 to Q.

REFERENCE

U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE

ENGINEERING DIVISION - DESIGN UNIT

STANDARD DWG. NO. ES-179

SHEET 3 OF 4

## SPILLWAYS: Examples Showing the Interrelation of Drawings ES-170 through ES-178

- C. Determine Hp
  - 1. Use ES-171, sheet 1. For b = 100 ft, z = 2, n = 0.04, L = 200 ft, and  $H_{ec} = 1.60$  ft, read  $H_{p} = 2.37$  ft. Then the head loss,  $h_f$  Ref, assuming the Reference Section is  $h_f$ <sub>Ref</sub> =  $H_p$  -  $H_{ec}$  = 2.37 - 1.60 = 0.77 ft
  - 2. Use ES-176, sheet 1 and a graphical procedure similar to that in Example 2 of ES-176. For  $H_{ec} = 1.60$  ft, L = 200 ft, and n = 0.035, obtain  $h_{f,0.035}/h_{f,0.04} = 0.87.$  $h_{f,0.035} = 0.87(h_{f,0.04}) = 0.87(0.77) = 0.67 \text{ ft}$ Then  $\Delta h_{f,n} = h_{f,0.035} - h_{f,0.04} = 0.67 - 0.77 = -0.10 ft$
  - 3. Use ES-176, sheet 4. For  $H_{ec}$  = 1.60 ft, L = 200 ft, and b = 70 ft, read  $h_{f,b}/h_{f,100} = 1.002$ . (This was obtained from a plot of b vs  $h_{f,b}/h_{f,100}$ .)  $h_{f,70} = 1.002(h_{f,100}) = 1.002(0.77) = 0.77 \text{ ft}$ Then  $\Delta h_{f,b} = h_{f,70} - h_{f,100} = 0.77 - 0.77 = 0$  ft
  - 4. Use ES-176, sheet 6. For  $H_{ec} = 1.60$  ft, L = 200 ft, and z = 3, read  $h_{f,z}/h_{f,z} = 0.999$ . (This was obtained from a plot of z vs  $h_{f,z}/h_{f,z}$ .)  $h_{f,3} = 0.999(h_{f,2}) = 0.999(0.77) = 0.77 \text{ ft}$ Then  $\Delta h_{f,z} = h_{f,3} - h_{f,2} = 0.77 - 0.77 = 0$  ft
  - 5. The total change in friction head loss,  $\Delta h_f$ , is given by  $\Delta h_f = \Delta h_{f,n} + \Delta h_{f,b} + \Delta h_{f,z} = -0.10 + 0 + 0 = -0.10 ft$ Then  $h_f = h_f \Big|_{Ref} + \Delta h_f = 0.77 - 0.10 = 0.67 \text{ ft}$  $H_p = H_{ec} + h_f = 1.60 + 0.67 = 2.27 \text{ ft}$

REFERENCE

U. S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

ENGINEERING DIVISION - DESIGN UNIT

STANDARD DWG, NO. ES-179 SHEET 4 OF 4

DATE \_ 2-68

. . .